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A STUDY OF LINT AND SEED DEVELOPMENT IN COTTON AS INFLUENCED BY ENVIRONMENTAL FACTORS[1]

D. G. STURKIE[2]

Cotton (*Gossypium hirsutum* L.) is the most important cash crop of the southern portion of the United States and its value is greatly influenced by the length and grade of staple, that is, its quality. Of these, the length of lint is recognized as the more important character by the cotton trade. The trade has long considered that cotton from different sections of the South varied in quality, and many trade names such as "benders," "rivers," and "peelers" are used to designate cotton from certain sections which are supposed to produce cotton of special merit. The lint of the cotton from these sections is longer than that from some others but the cause of this difference is unknown. The determination of the conditions affecting the length of the fibers is of special importance in the eastern portion of the cotton belt because much of the cotton now produced there is short lint while that formerly produced was long lint. There has been very little research in this country dealing with the influence of environment on the length of the fiber. The most notable investigations of this nature have been made by Balls working with Egyptian cotton in Egypt, by Burd working with Sea Island cotton in the West Indies, and by Parsons working with Sea Island cotton in Trinidad.

Balls (1)[3] concluded that any conditions that would produce a noticeable effect in the physiological functions of the plant might affect the length and strength of the lint. By working with cotton which was irrigated, he found that a deficiency in the soil moisture during the first 23 days after a blossom appeared was associated with a shortening of the fiber produced by the boll which developed from this blossom. A deficiency in soil moisture during the period from 23 days after blossoming to maturity was associated with a weakening of the fiber. His histological studies seemed to support the conclusions regarding the time periods when these characters were likely to be most seriously affected by any adverse edaphic or climatic factors. Balls suggested that a rise of the water table sufficient to destroy part of the root system would shorten the lint that was then developing in length and weaken that which was filling. Burd (3, 4) reported that in the West Indies a heavy rainfall about 19 days after flowering seriously lowered the mean maximum length of lint. Harland (6) reported that F. S. Parsons found that soil moisture determined the length of lint.

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[1] Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Also presented as a thesis to the Michigan State College in partial fulfillment of the requirement for the degree of doctor of philosophy. Received for publication February 3, 1933.

[2] Assistant Agronomist. The author wishes to express his appreciation to the authorities of the Michigan State College and the Alabama Polytechnic Institute for making this investigation possible through their cooperation and to the following individuals whose assistance was especially valuable: Dean E. A. Bessey and Dr. R. P. Hibbard of the Botany Department of Michigan State College for help in outlining the problem and for painstaking reviews and helpful suggestions in writing the manuscript; Dean M. J. Funchess of the Alabama Agricultural Experiment Station for many helpful suggestions and criticisms in planning and conducting the experiment; Director W. E. Ayers of the Delta Station, Stoneville, Mississippi, for supplying soil; and Dean R. Y. Winters of the North Carolina Experiment Station for the strain of cotton used.

[3] Reference by number is to "Literature Cited," p. 24.

Youngblood (12), by studying the reports on length of lint from various sections of the South and by correlating length of lint with the soil type, concluded that longer lint came from the more fertile soils. He noted an exception in the case of cotton from the Piedmont region. These soils are often badly eroded and low in fertility, yet they produced longer lint than did the Coastal Plain soils which are considered to be more fertile. Funchess (5), after studying the results of variety tests in Alabama, concluded that soil type does not affect the length of lint. He showed that the area that produced cotton with the longest lint in the state one year produced cotton with the shortest lint the following year. He suggested that this extreme difference in lint length might be due to a difference in rainfall for the two years in question.

Several workers have studied other factors that might affect the length of lint. Ludwig (9) stated that "late defoliation did not affect the length of lint but if done several weeks before maturity the strength of the fiber was lowered." The earliest date of defoliation used was on August 20, which was probably after most of the bolls were old enough for the fibers to have reached their maximum length. Kearney and Harrison (8) state that "the bolls higher up the stalk had a longer fiber than those nearer the base." They do not make any physiological explanation of this, nor do they take any physiological factors into consideration.

Barre, Armstrong, and Bennett (2) state that "even though the longest fibers have practically ceased growth at 30 days, the fiber arrays show that elongation of other fibers must continue until maturity of the boll at 50 days." The most rapid rate of growth was during the first 7 days. Hawkins and Serviss (7) concluded that elongation of Acala cotton fibers was complete in 21 to 24 days after flowering and that of Pima cotton in 27 to 30 days. The most rapid elongation was about the twenty-first day in the Pima and from the fifteenth to the eighteenth day in the Acala. Balls (1), by making histological studies, found that fibers reached their maximum length about the twenty-fourth day and made their most rapid elongation around the fifteenth day following flowering. They began filling with cellulose about the twenty-first day.

Other workers have studied still other physiological problems of cotton, but their experiments do not deal specifically with factors influencing lint development. As may be seen from the literature reviewed, the problem of the influence of environmental conditions on the length of lint and other properties of the fiber is far from solved. Most of the work dealing with this problem has been done in Egypt and the West Indies. The type of cotton used and the conditions under which the experiments were conducted, however, differ from those in this country. A determination of the causes of variations in staple length should be of value to the agronomist, the plant breeder, the farmer, and the cotton trade, since each is interested in the quality of the product obtained.

It is the purpose of this paper to report results of experiments dealing with the length of lint as influenced by soil moisture, soil type, atmospheric humidity, evaporation, and temperature. The effects of these environmental factors on weight of boll, number of seed per boll, weight per seed, weight of lint per seed, weight of lint per unit weight of seed,[4] and percentage of lint are also reported.

EXPERIMENTAL METHODS

A pure-line strain of the Mexican Big Boll variety of cotton which had bred true to type for 12 years was obtained from the North Carolina Agricultural Experiment Station for use in this experiment. This is a typical variety of American Upland cotton. The strain used, when grown under favorable conditions, produces a staple of 28.6 mm (1⅛ inches) in length.

All cotton was fertilized at the rate of 1,000 pounds of superphosphate, 500 pounds of nitrate of soda, and 100 pounds of muriate of potash per acre, based on the surface area.

SOIL TYPE STUDIES

The methods of Veihmeyer and Hendrickson (10) and of Veihmeyer (11) for studying water relations of plants were used in this study. Large galvanized iron cans, 30 inches in diameter and 24 inches deep, holding approximately 1,000 pounds of soil each, were used as containers. The cans were placed in a trench so that the tops were level with the surface of the soil and so arranged that they could be weighed. Two 8-inch layers of subsoil and one 6-inch layer of top soil, as they occurred in the field, were placed in the cans.

The moisture content of the soil was not kept constant. After it had lost considerable moisture, but before the plants had begun to wilt, water was added until the water-holding capacity was reached. Veihmeyer and others have shown that it is impossible to moisten a soil uniformly to a definite moisture content below that of the water-holding capacity. Furthermore, it has been shown that a plant uses water over a wide range of moisture conditions, extending from the water-holding capacity to the wilting point. Thus, by adding water until the soil moisture was at the point of the water-holding capacity, it was possible to wet all of the soil and not limit the area of root growth.

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[4] The weight of lint per unit weight of seed is obtained by dividing the weight of lint per seed by the weight per seed.

Two soils of very different type from areas that produce cotton which the trade considers to be widely different were used. One of the soils was a Norfolk sandy loam and came from a field at Auburn, Ala. This is a shallow infertile soil, coarse in texture, very low in organic matter, and not uniform. The top soil is usually 4 to 8 inches in depth and is underlaid by a friable yellow clayish subsoil. The cotton produced on this soil is considered to be poor in quality and is often sold at a discount. The other soil was classed as Deer Creek loam and came from a field on the Delta Experiment Station at Stoneville, Miss. This is a deep fertile alluvial soil, fine in texture, rich in organic matter, and quite uniform throughout. Cotton produced on this soil is considered to be of high quality and usually brings a premium on the market. If soil type measurably affects the quality of cotton, the use of two such extreme types should demonstrate this effect.

Thirteen cans containing two plants each were used for each soil type. This gave a total of 26 plants in each soil type from which results were obtained. Plants were grown outside of the trench to make conditions as nearly normal as possible. This experiment was located adjacent to the plats used in the soil moisture studies so that the records for temperature, humidity and evaporation were applicable to both experiments.

SOIL MOISTURE STUDIES

In this study a method somewhat similar to that of Balls (1) was used. Field plats 20 by 20 feet in size, separated by 2-foot alleys, were irrigated to produce varying conditions of moisture. Each plat was surrounded by a wall of galvanized iron placed 2 feet deep in the ground to prevent the roots of the plants from feeding outside of the plats. A canvas cover supported by a wooden frame built over these plats protected them from rain. When it was not raining the plats were uncovered. The cotton was spaced 2 feet apart with two plants per hill in rows 4 feet apart, giving 100 plants per plat. Cotton plants were grown in the alleys and on the outside borders of all plats to approximate normal field conditions.

The various plats were irrigated on the dates shown in Table 1, 1 inch of water being used at each irrigation. This was applied at night or on a cloudy afternoon to prevent excessive water losses by evaporation. Each plat was laid off in 16 sections and small banks of soil were thrown up at the borders of these to confine the water and prevent it from forming pools in the lower areas. This made it possible to irrigate the plats uniformly. The water was measured by a standard water meter.

Soil moisture records were obtained by taking samples of soil at three depths, *viz.*, 0 to 8, 8 to 16, and 16 to 24 inches so that the moisture content could be determined for 8-inch layers from 0 to 24 inches or for the entire depth. Only one sample per plat was obtained each week and in case the plat was to be irrigated this was taken before the irrigation. It was considered undesirable to take more samples in a plat of this size because of the danger of injuring the roots of the plants. The samples were always taken from between the rows. It is realized that these few samples are not sufficient to give results with a great degree of accuracy, but they do offer some indication as to the soil moisture conditions under which the plants grew.

TABLE 1.—*The dates of irrigation of the field plats.**

1928		1929		1930			
Plat No.		Plat No.		Plat No.			
1	4	1	4	1	4	5	6
June 20	June 20	June 12		June 25	June 25		June 25
June 27		June 19		July 2			July 2
July 4		June 26		July 9			
July 11		July 3		July 16		July 16†	
July 18		July 10		July 23		July 23†	
July 25		July 17		July 30		July 30	July 30‡
Aug. 1		July 24		Aug. 6		Aug. 6	
Aug. 8		July 31	July 31	Aug. 13		Aug. 13	
Aug. 15	Aug. 15	Aug. 7		Aug. 20	Aug. 20	Aug. 20	Aug. 20
Aug. 22		Aug. 14		Aug. 27		Aug. 27	Aug. 27
Aug. 29		Aug. 21		Sept. 3		Sept. 3	Sept. 3
Sept. 5		Aug. 28		Sept. 10			
Sept. 12							
Sept. 19							
Sept. 26							
Oct. 3							
Oct. 10	Oct. 10						

1931				1932			
Plat No.				Plat No.			
1	4	5	6	1	4	5	6
July 1	July 1		July 1	July 6	July 6		July 6
July 8	July 8		July 8	July 13†	July 13		July 13†
July 15			July 15	July 20†			July 20†
July 22			July 22	July 27			July 27
July 29			July 29	Aug. 3		Aug. 3†	
Aug. 5		Aug. 5†		Aug. 10†		Aug. 10†	
Aug. 12		Aug. 12†		Aug. 17		Aug. 17	
Aug. 19		Aug. 19		Aug. 24†		Aug. 24†	
Aug. 26		Aug. 26		Aug. 31		Aug. 31	
Sept. 2	Sept. 2	Sept. 2		Sept. 7		Sept. 7	
Sept. 9		Sept. 9		Sept. 14		Sept. 14	
Sept. 16				Sept. 21†		Sept. 21†	
Sept. 23		Sept. 23		Sept. 28		Sept. 28	
Sept. 30							
Oct. 7							

*Irrigated at the rate of 1 inch on each date except where otherwise noted.
†Irrigated at the rate of 2 inches.
‡Flooded by rainstorm.

ATMOSPHERIC RECORDS

Temperature and humidity records were obtained from a hygrothermograph, placed in a covered lattice house, 6 inches from the surface of the soil and adjacent to the plats. Evaporation was measured by means of standardized atmometers placed between the rows of cotton in such a manner that the white porous cups were about 1 foot above the surface of the soil. Evaporation records were kept within each plat and outside of them. Atmometers with black cups were also used outside the plats to determine the effect of sunshine.

BLOSSOM AND BOLL RECORDS

The blossoms were marked with a numbered tag as they appeared, this number serving as a means of identification in all later studies. If a blossom was shed or if the boll rotted, a notation was made. When the first open bolls appeared, a chart was made which showed the exact location of the stalk and the position of each boll on the stalk. Each boll was harvested separately and the cotton was permitted to come to a uniform moisture content before any measurements were made. Records were kept by number only, thus when measuring a given boll the operator had no knowledge of its history. Only after all measurements were made was the source of the boll recorded.

METHOD OF MEASURING LINT

The length of lint was determined by a method similar to the one used by Balls. The lint was combed out from the seed in a fan-shaped array and the length of lint measured with a pair of dividers. Measurement was always made to the dense portion of the halo and not to the fringe of long fibers. Usually five or more measurements were made on each boll and at least one seed from each lock was used. The average of these measurements was recorded as the length of lint from this boll. Balls has shown that this is the most accurate way of determining rapidly the average length of lint. A careful check of this method made at the beginning of the experiment showed that the probable error was very small.

Balls has shown that the length of Egyptian cotton staple obtained by this method is approximately 21% less than that obtained by cotton classers in pulling. The results obtained in this investigation indicate that the method used by Balls does give smaller values than are obtained by the pulling method, although the difference between the values obtained by the two methods does not seem to be as great as 21% for the strain of cotton used in this test. Therefore, the lint lengths reported in this paper are shorter than would have been obtained had the pulling method been used.

The measurements for each season were made in all cases by the same person.

METHODS USED IN OTHER DETERMINATIONS

The seed cotton was weighed and the cotton was then ginned on a roller gin for ginning boll lots. After ginning, the seed were counted and the lint was weighed. The weight of seed, percentage of lint, average weight per seed, and average weight of lint per seed were calculated.

RESULTS

The treatments used in this study and the total number of bolls obtained in each treatment are shown in Tables 2, 3, and 4. It may be observed that this number varied from 168 in the case of cotton grown on the Norfolk sandy loam in cans to 960 in the case of the field plat irrigated each week. The results are reported as averages of 7-day periods in order to reduce the size of the tables in publication.

LENGTH OF LINT STUDIES

Influence of soil type.—The type of soil on which cotton is grown has no direct influence on the length of lint. This is clearly shown by the data presented in Table 2 which are the results obtained in a study extending over a period of 5 years. These data show no consistent differences in the length of lint produced on the two soils, the maximum difference for any one blooming date being 1.1 mm and for any one year 0.5 mm. These results are reported graphically in Fig. 1. An examination of this figure will reveal the fact that there was no marked tendency for the lint from cotton grown on either soil to be longer than that from the other.

It is quite generally known that cotton from different sections of the South varies in length. Youngblood attributed this to soil type or fertility, while Funchess showed that a given soil may produce the longest lint in the state one year and the shortest the next, and he attributed this to rainfall. The results of this experiment do not agree with those of Youngblood, but they do agree with the view that Funchess advanced. Under natural conditions the two soils used in this experiment produce cottons differing greatly in value; however, when planted to the same variety and placed under the same environment they produced cotton that was identical. If one section produces cotton that is quite different from that produced in another section, it seems probable that it is due either to a difference in variety or to a difference in soil moisture. The soil type in itself had no effect on the cotton, but of course soil types vary in their ability to retain moisture and in so doing might influence the quality of cotton produced. One cannot always be certain that one soil will produce a longer staple than will another since any soil is likely to produce shorter staple in a dry year.

Influence of temperature, humidity, or evaporation.—Graphs of the data obtained in this experiment are presented in Fig. 2, and show that there was no correlation between the length of lint and temperature, humidity, or evaporation.

Influence of soil moisture.—This experiment was conducted in the field where the plats were irrigated at varying intervals so that some plants were grown under relatively moist conditions, while others were grown under relatively dry conditions. Four plats were irrigated at the rate of 1 inch of water at each irrigation. This was applied each week to plat 1, every 2 weeks to plat 2, every 4 weeks to

TABLE 2.—*The averages by 7-day periods of the determinations made*

Date of blooming	Grown in Norfolk sandy loam soil							
	Total number of bolls	Weight per boll, gms	Length of lint, mm	Number of seeds per boll	Per cent lint	Weight per seed, gms	Weight of lint per seed, gms	Weight of lint per gram of seed, gms
				1928				
July 11......	—	—	—	—	—	—	—	—
July 18......	28	7.44	24.9	31.9	38.6	0.143	0.090	0.629
July 25......	54	7.21	24.9	32.7	38.9	0.135	0.086	0.637
Aug. 1......	64	7.42	25.2	34.8	38.7	0.131	0.083	0.634
Aug. 8......	58	7.28	24.9	34.1	37.6	0.133	0.080	0.602
Aug. 15.....	15	5.59	23.9	30.1	37.6	0.116	0.070	0.603
Weighted av.	219	7.21	24.9	33.4	38.4	0.131	0.083	0.634
				1929				
July 10......	15	7.59	25.3	34.1	38.9	0.136	0.087	0.640
July 17......	96	7.25	24.5	35.2	40.1	0.123	0.083	0.675
July 24......	42	7.65	24.1	36.5	40.3	0.125	0.084	0.672
July 31......	15	6.85	23.9	32.9	38.5	0.128	0.080	0.625
Aug. 7......	—	—	—	—	—	—	—	—
Aug. 14.....	—	—	—	—	—	—	—	—
Weighted av.	168	7.34	24.4	35.2	39.9	0.125	0.083	0.664
				1930				
June 25.....	—	—	—	—	—	—	—	—
July 2.......	45	6.41	24.9	26.9	39.3	0.145	0.094	0.648
July 9.......	64	5.73	25.7	24.9	38.2	0.142	0.088	0.620
July 16......	48	5.39	24.7	27.0	40.6	0.120	0.081	0.675
July 23......	37	5.34	24.2	27.0	40.0	0.119	0.079	0.664
July 30......	23	5.50	24.7	29.8	38.5	0.113	0.071	0.628
Aug. 6......	6	6.31	25.5	31.6	39.1	0.122	0.078	0.639
Weighted av.	223	5.72	25.0	26.8	39.3	0.130	0.084	0.646
				1931				
July 8.......	11	6.52	26.6	24.2	39.9	0.162	0.107	0.660
July 15......	29	7.70	26.0	31.0	41.7	0.145	0.104	0.717
July 22......	49	7.25	25.3	31.2	41.8	0.135	0.097	0.719
July 29......	25	7.26	26.1	33.2	39.5	0.132	0.086	0.652
Aug. 5......	36	6.34	25.9	32.1	38.0	0.122	0.075	0.615
Aug. 12.....	12	5.87	24.8	30.8	41.9	0.111	0.080	0.721
Aug. 19.....	6	6.53	25.0	33.2	41.0	0.116	0.081	0.698
Weighted av.	168	6.96	25.7	31.2	40.5	0.133	0.090	0.677
				1932				
July 13......	32	6.31	27.2	27.6	35.9	0.147	0.082	0.558
July 20......	87	5.81	26.6	28.5	37.6	0.127	0.077	0.606
July 27......	58	5.67	25.6	30.4	40.1	0.112	0.075	0.670
Aug. 3......	—	—	—	—	—	—	—	—
Aug. 10.....	—	—	—	—	—	—	—	—
Weighted av.	177	5.85	26.4	29.0	38.1	0.126	0.077	0.611

*The 7-day period was for 3 days before and 3 days after the date shown.

*on cotton grown on two different soil types in the years 1928–32, inclusive.**

Grown in Deer Creek loam soil

Total number of bolls	Weight per boll, gms	Length of lint, mm	Number of seeds per boll	Per cent lint	Weight per seed, gms	Weight of lint per seed, gms	Weight of lint per gram of seed, gms
			1928				
25	6.42	24.9	30.1	38.6	0.131	0.082	0.626
103	7.75	25.0	35.9	39.5	0.131	0.085	0.649
136	7.70	25.1	34.6	38.6	0.137	0.086	0.628
62	7.58	25.2	35.6	37.6	0.133	0.080	0.602
32	6.00	24.3	31.2	39.2	0.117	0.075	0.641
—	—	—	—	—	—	—	—
358	7.45	25.0	34.5	38.7	0.132	0.084	0.636
			1929				
7	7.50	24.4	36.4	39.3	0.125	0.081	0.648
74	8.03	23.8	38.5	40.1	0.125	0.084	0.672
39	7.29	24.3	34.9	40.6	0.124	0.085	0.685
45	7.37	24.7	33.3	38.8	0.135	0.086	0.637
36	7.47	23.9	35.9	40.1	0.125	0.084	0.672
10	6.71	23.6	34.8	38.4	0.119	0.074	0.622
211	7.57	24.1	36.0	39.9	0.126	0.084	0.667
			1930				
9	5.92	24.9	26.4	36.0	0.144	0.081	0.563
19	6.75	25.0	29.6	38.8	0.140	0.089	0.636
43	5.71	25.6	24.0	37.0	0.150	0.088	0.587
90	5.80	24.7	26.0	40.0	0.134	0.089	0.664
132	5.73	24.2	27.0	40.3	0.127	0.086	0.677
42	5.55	24.3	26.7	39.5	0.126	0.082	0.651
16	5.31	24.4	27.1	40.3	0.117	0.079	0.675
351	5.76	24.6	26.5	39.6	0.131	0.086	0.656
			1931				
8	7.15	26.8	25.5	39.6	0.169	0.111	0.657
43	7.50	25.9	31.1	41.2	0.142	0.099	0.697
98	6.85	25.4	31.3	41.9	0.127	0.092	0.724
61	6.51	25.7	31.0	40.4	0.125	0.085	0.680
67	6.05	26.1	29.3	42.5	0.119	0.088	0.739
25	4.27	24.5	22.0	42.6	0.111	0.083	0.748
4	4.11	25.2	22.5	41.4	0.107	0.076	0.710
306	6.46	25.6	29.7	41.5	0.127	0.090	0.709
			1932				
41	6.28	27.2	28.5	34.9	0.144	0.077	0.535
99	6.64	27.0	29.5	38.0	0.139	0.085	0.612
59	6.65	26.7	31.6	39.5	0.128	0.084	0.656
16	6.04	26.5	29.4	39.1	0.125	0.080	0.640
7	6.58	26.7	32.7	39.9	0.120	0.080	0.667
222	6.53	26.9	30.0	38.0	0.135	0.083	0.615

plat 3, and every 8 weeks to plat 4. The dates of irrigation are shown in Table 1. The results are reported only for plats 1 and 4; the results for plats 2 and 3 being omitted for the sake of brevity, since they are intermediate between those of plats 1 and 4 and only substantiate the conclusions that may be drawn from the latter. The results are recorded in Table 3.

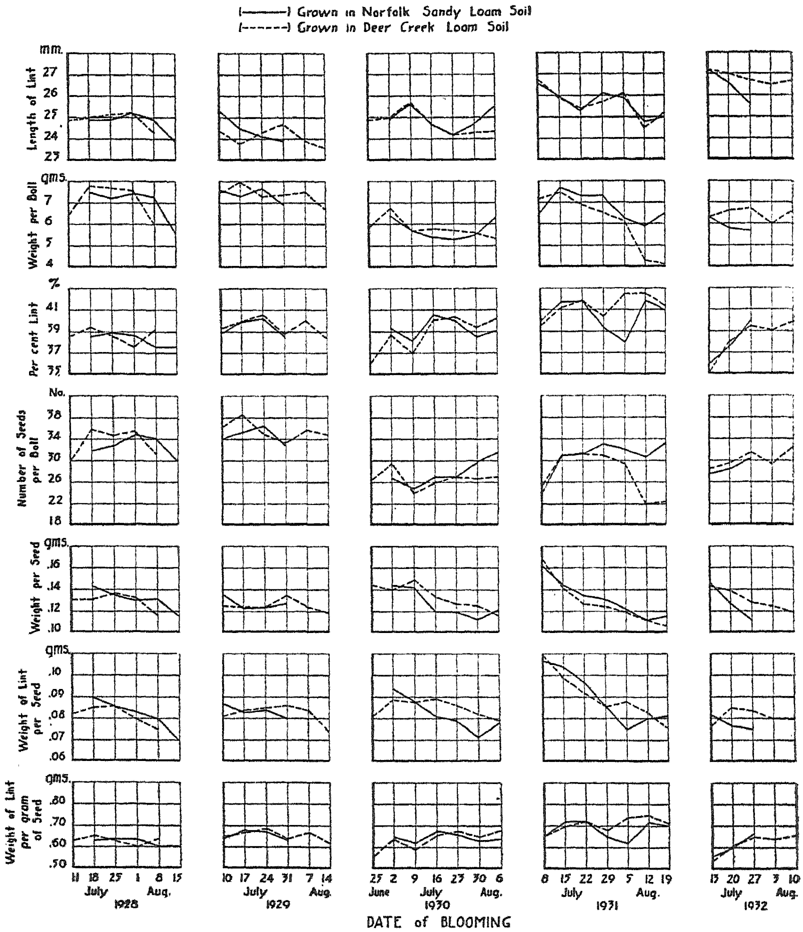

FIG. 1.—The average results by 7-day periods of determinations of the length of lint, weight per boll, percentage lint, number of seeds per boll, weight per seed, weight of lint per seed, and weight of lint per gram of seed made on cotton grown in Norfolk sandy loam soil and on that grown in Deer Creek loam soil in each of the 5 years of this study. The 7-day period was for 3 days before and 3 days after the date shown. The dates recorded are the dates on which the blossoms opened that produced the bolls on which the determinations were made.

It is obvious from the data presented in Table 3 that there was a marked relation between lint length and the amount of soil moisture available to the plant while the lint was elongating. The average length of lint produced on plat 1 which was irrigated frequently was longer than that on plat 4 which was irrigated every 8 weeks each of the 5 years the experiment was conducted. In 1928, this difference was 1.2 mm; in 1929, 1.2 mm; in 1930, 1.5 mm; in 1931, 1.7 mm; and in 1932, 2.8 mm. The average difference is 1.7 mm, or approximately 1/15 of an inch. These data are illustrated in Fig. 3.

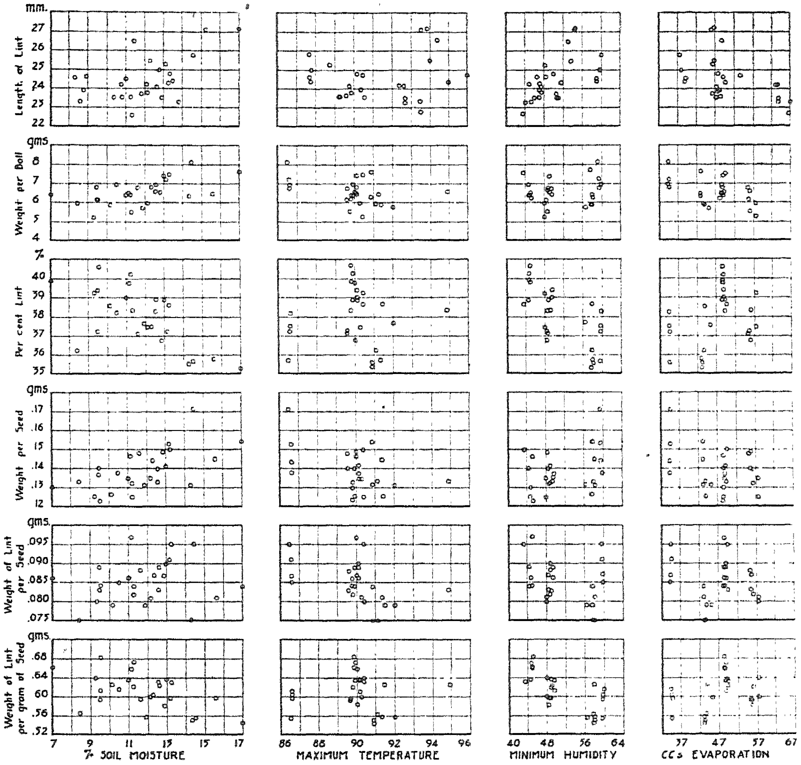

FIG. 2.—Scattergram of the relation of average length of lint, weight per boll, percentage lint, weight per seed, weight of lint per seed, and weight of lint per gram of seed to the percentage soil moisture, maximum temperature, minimum humidity, and cc of evaporation for the plats irrigated at different frequencies in each of the 5 years. The length of lint is correlated with the average for 14 days after blooming for the various factors. The other determinations are correlated with the average for 42 days after blooming for the various factors

The relation between length of lint and soil moisture is further emphasized by a detailed study of the data by days from which the data in Table 3 were averaged. The daily data show that the average length of lint in bolls dated July 30, 1928, was 25.8 mm for plat 1 and only 23.3 mm for plat 4. The length of lint from plat 4 was increased by the irrigation of August 15, bolls dated August 5 having a lint length of 25.8 mm which equals the length of lint from bolls of the

TABLE 3.—*The averages by 7-day periods of the determinations made on*

Date of blooming	Plat 1 irrigated each week							
	Total number of bolls	Weight per boll, gms	Length of lint, mm	Number of seeds per boll	Per cent lint	Weight per seed, gms	Weight of lint per seed, gms	Weight of lint per gram of seed, gms
				1928				
July 25	56	7.80	25.3	29.3	36.0	0.171	0.096	0.561
Aug. 1	109	8.08	25.8	30.3	36.5	0.169	0.097	0.574
Aug. 8	252	8.56	26.1	31.4	35.4	0.176	0.097	0.551
Aug. 15	79	7.39	25.4	29.5	35.3	0.162	0.089	0.549
Aug. 22	35	7.16	24.9	28.8	36.9	0.157	0.092	0.586
Weighted av.	531	8.12	25.8	30.5	35.7	0.171	0.095	0.556
				1929				
July 3	16	7.85	25.8	29.2	37.4	0.168	0.101	0.601
July 10	132	8.41	26.4	32.8	36.9	0.162	0.095	0.586
July 17	144	7.98	25.9	34.9	37.2	0.144	0.085	0.590
July 24	291	7.06	24.5	31.4	39.9	0.135	0.090	0.667
July 31	297	7.10	23.9	31.8	40.3	0.133	0.090	0.677
Aug. 7	34	7.05	23.9	30.5	39.1	0.141	0.091	0.645
Aug. 14	16	6.81	24.4	31.1	36.7	0.139	0.080	0.576
Weighted av.	930	7.42	24.8	32.2	38.9	0.141	0.090	0.638
				1930				
July 2	125	6.64	24.0	30.4	37.0	0.138	0.081	0.587
July 9	178	6.19	24.4	26.1	35.9	0.152	0.085	0.559
July 16	315	7.22	23.4	29.9	38.1	0.149	0.092	0.617
July 23	157	7.28	24.4	29.8	37.0	0.154	0.090	0.584
July 30	123	6.68	25.8	29.1	35.5	0.148	0.081	0.547
Aug. 6	27	5.99	23.7	27.0	39.0	0.135	0.087	0.644
Weighted av.	925	6.85	24.2	29.0	37.1	0.148	0.088	0.595
				1931				
July 8	18	6.57	25.3	25.5	39.1	0.157	0.101	0.643
July 15	61	6.90	24.8	26.7	38.8	0.158	0.100	0.633
July 22	169	6.79	24.6	26.6	38.9	0.156	0.099	0.635
July 29	278	7.65	24.8	30.7	38.6	0.153	0.096	0.627
Aug. 5	234	8.25	25.9	34.1	38.6	0.149	0.093	0.624
Aug. 12	176	7.47	26.2	32.7	38.8	0.140	0.089	0.636
Aug. 19	24	7.28	25.1	30.9	39.0	0.144	0.092	0.639
Weighted av.	960	7.54	25.3	30.8	38.7	0.150	0.095	0.633
				1932				
July 13	130	7.00	27.7	28.6	34.9	0.159	0.085	0.535
July 20	288	7.59	27.2	30.6	35.2	0.161	0.087	0.540
July 27	308	8.12	26.5	34.8	36.0	0.149	0.084	0.564
Aug. 3	73	8.23	27.4	34.5	33.6	0.158	0.080	0.506
Aug. 10	133	7.46	27.4	33.8	35.3	0.143	0.078	0.545
Weighted av.	932	7.71	27.1	32.5	35.3	0.154	0.084	0.545

*The 7-day period was for 3 days before and 3 days after the date shown.

*cotton irrigated at different frequencies in the years 1928–32, inclusive.**

Plat 4 irrigated each 8 weeks

Total number of bolls	Weight per boll, gms	Length of lint, mm	Number of seeds per boll	Per cent lint	Weight per seed, gms	Weight of lint per seed, gms	Weight of lint per gram of seed, gms
1928							
101	6.86	24.4	30.7	38.6	0.137	0.086	0.628
152	7.52	24.3	32.3	38.3	0.144	0.089	0.618
135	7.47	25.7	32.0	37.1	0.147	0.087	0.592
100	5.56	23.8	28.8	39.7	0.116	0.077	0.664
—	—	—	—	—	—	—	—
488	6.97	24.6	31.2	38.2	0.138	0.085	0.616
1929							
101	6.40	23.1	27.2	40.2	0.141	0.095	0.674
126	7.34	24.0	31.0	39.6	0.143	0.094	0.657
69	7.00	23.8	31.9	38.7	0.134	0.085	0.634
64	6.72	23.8	31.5	38.8	0.130	0.083	0.638
22	5.24	23.0	26.9	37.9	0.121	0.074	0.612
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
382	6.80	23.6	30.0	39.4	0.137	0.089	0.650
1930							
110	5.05	22.2	24.9	38.6	0.124	0.078	0.629
77	4.86	23.9	22.4	37.3	0.136	0.081	0.596
203	4.95	22.3	24.4	40.4	0.121	0.082	0.678
12	6.03	22.6	28.8	39.1	0.127	0.082	0.646
18	5.24	24.8	26.5	35.1	0.128	0.069	0.539
—	—	—	—	—	—	—	—
420	5.00	22.7	24.4	39.2	0.125	0.080	0.640
1931							
12	6.11	24.4	26.6	37.6	0.143	0.087	0.608
55	5.93	24.0	28.4	39.9	0.126	0.083	0.659
164	6.16	22.7	29.6	41.6	0.122	0.087	0.713
91	6.37	23.8	30.5	40.3	0.125	0.084	0.672
46	6.11	25.1	30.3	40.0	0.121	0.081	0.669
8	5.64	25.0	29.8	40.2	0.113	0.076	0.673
2	5.50	24.5	35.0	36.6	0.099	0.057	0.576
378	6.15	23.6	29.7	40.7	0.123	0.084	0.683
1932							
125	5.56	24.1	26.4	37.0	0.133	0.078	0.586
262	6.16	24.8	29.4	38.5	0.129	0.081	0.628
177	5.76	23.8	29.7	40.1	0.116	0.078	0.672
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
564	5.90	24.3	28.8	38.7	0.126	0.079	0.627

same date on plat 1. In 1929, the average length of lint produced from blossoms opening on July 5 on plat 1 was 25.5 mm while that produced on plat 4 was only 22.7 mm. In bolls dated July 16 the average length was 25.8 mm and 23.8 mm for plats 1 and 4, respectively. Those dated July 28 produced lint that was identical in

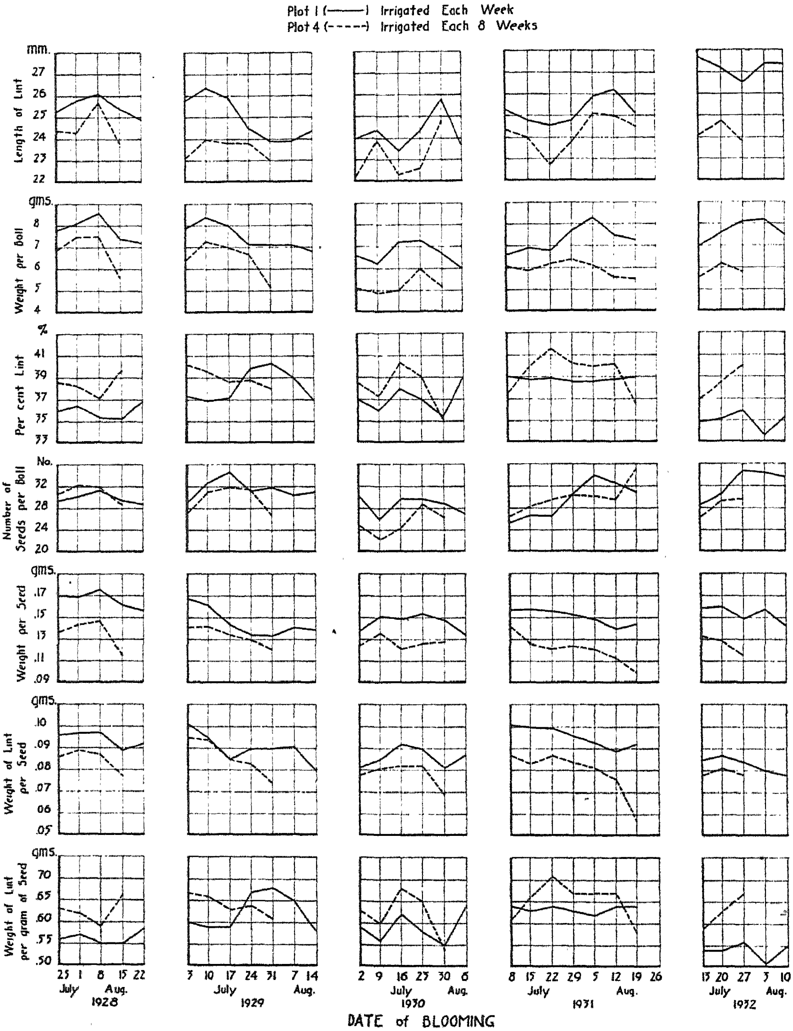

FIG. 3.—The average results by 7-day periods of determinations of the length of lint, weight per boll, percentage lint, number of seeds per boll, weight per seed, weight of lint per seed, and weight of lint per gram of seed made on cotton irrigated each week and on that irrigated each 8 weeks in the 5 years of this study. The 7-day period was for 3 days before and 3 days after the date recorded. The dates recorded are the dates on which the blossoms opened that produced the bolls on which the determinations were made.

length on both plats. It may be noted that plat 4 was irrigated on July 31, 1929. This irrigation did not markedly increase the length of lint as in 1928. This difference may be explained by a study of the climatic conditions. In 1928, the irrigation was followed by cool moist weather which induced a low rate of evaporation, *viz.*, only 25 cc per day from standardized black atmometers for the 14 days following irrigation. In 1929, the weather was hot and dry for 14 days following irrigation and the evaporation averaged 38 cc per day. Thus, in 1928, the water was very effective in increasing the length of lint because it did not evaporate so rapidly and could be effectively used by the plants, whereas in 1929 it evaporated so rapidly that its effectiveness was largely lost because the plants were placed under a stress for water before the lint had completed its elongating. This difference in the two seasons is illustrated very strikingly by the results for plat 1. For example, in 1928, 1 inch of water per week was sufficient to maintain the moisture content of the soil at a high level and there was no marked shortening of the lint as the season advanced. In 1929, the moisture content dropped rapidly, from 14.7% in the first 24 inches of soil on July 24 to 8.7% on August 14, even though the plat was being irrigated each week. This resulted in a short lint being produced during the later period of growth.

The results for the first 2 years of the experiment showed that the soil moisture affected the length of lint and indicated that it was possible to produce a long or short lint at any time in the season by properly regulating the soil moisture. In order to test this, two additional plats were started in 1930. One of these, plat 5, was kept dry during the early season of growth and moist during the late season. The other, plat 6, was kept moist during the early period of growth and dry during the late. It was expected that the lint from the early bolls on plat 6 would be long while that from plat 5 would be short. The reverse of this should be true for the lint from the late bolls. The results are recorded in Table 4 and reported graphically in Fig. 4.

The data show that the length of lint on the two plats followed the predicted results very closely in 1931 and 1932 but did not do so in 1930. It may be noted that in 1930 the lint on plat 6 in the early season was of medium length, that in the middle of the season it was short, and that for the remainder of the season it was long. The lint on plat 5 was short in the early bolls and long in others. This variation from the predicted results was caused by stopping irrigation too early on plat 6, since by July 2, the date irrigation was stopped, only a very few bolls had been formed and these were still so young that most of their development was completed under the dry conditions prevailing on plat 6 after that date. The moisture content of the soil on plat 6 declined very rapidly resulting in the production of short lint. Also plat 6 was flooded on July 30 by water breaking over the edge during a severe rainstorm. This accidental wetting resulted in an increase in the length of lint. Bolls dated July 17 produced lint only 21 mm long, while those dated July 23 produced lint 24.6 mm long. On the other hand, irrigation was started so early (July 16) on plat 5 that only a small portion of the bolls produced grew under

TABLE 4.—*The averages by 7-day periods of the determinations made on*

Date of blooming	Plat 5 Irrigated in late season of growth							
	Total number of bolls	Weight per boll, gms	Length of lint, mm	Num- of seeds per boil	Per cent lint	Weight per seed, gms	Weight of lint per seed, gms	Weight of lint per gram of seed, gms.
				1930				
July 2......	131	5.92	22.3	29.1	39.7	0.123	0.081	0.659
July 9......	60	5.59	25.2	22.0	34.5	0.166	0.088	0.530
July 16......	305	6.89	24.5	28.7	36.6	0.152	0.088	0.579
July 23......	37	7.57	25.1	28.8	35.1	0.170	0.092	0.541
July 30......	14	7.45	25.1	29.9	33.7	0.165	0.084	0.509
Aug. 6......	24	7.65	25.1	29.2	35.2	0.170	0.092	0.541
Aug. 13......	18	7.89	25.5	30.5	36.0	0.166	0.093	0.560
Weighted av.	589	6.66	24.2	28.2	36.8	0.149	0.087	0.584
				1931				
July 8......	19	5.81	25.1	23.6	39.6	0.149	0.098	0.658
July 15......	47	6.55	24.0	27.2	40.8	0.143	0.098	0.685
July 22......	78	6.18	24.1	26.0	40.6	0.141	0.097	0.688
July 29......	29	7.05	25.1	28.5	38.4	0.152	0.095	0.625
Aug. 5......	20	6.82	25.6	26.2	38.1	0.161	0.099	0.615
Aug. 12......	24	7.20	26.6	27.5	39.0	0.160	0.102	0.638
Aug. 19......	—	—	—	—	—	—	—	—
Weighted av.	217	6.51	24.7	26.6	39.8	0.147	0.097	0.660
				1932				
July 13......	63	4.89	24.4	22.6	35.2	0.140	0.076	0.543
July 20......	245	6.05	25.0	27.2	36.9	0.141	0.082	0.582
July 27......	169	7.13	26.0	31.2	35.3	0.148	0.081	0.547
Aug. 3......	49	7.52	27.6	30.5	33.1	0.166	0.082	0.494
Aug. 10......	7	7.39	26.9	27.6	36.0	0.148	0.083	0.561
Weighted av.	533	6.41	25.5	28.2	35.8	0.145	0.081	0.559

*The 7-day period was for 3 days before and 3 days after the date shown.

drouthy conditions. The length of lint by days and the soil moisture for plat 6 in 1930 are shown in Fig. 5. It may be noted that the length of lint closely follows the soil moisture content. Although the results for 1930 were not as predicted due to errors in treatment of the plats, they further demonstrate that the length of lint is influenced by the soil moisture conditions.

The results for 1931 and 1932 were as predicted since the errors made in 1930 were avoided. The lint from plat 6 was longest and that from plat 5 was shortest during the early season. Thus, the results in 1930, 1931, and 1932 proved that it was possible to produce a long or a short lint during any portion of the season by regulating the soil moisture and further indicated that the soil moisture was the most important factor affecting the length of lint.

It may be noted that the last few bolls produced during the season *cotton irrigated at different stages of growth in the years 1930–32, inclusive.**

Plat 6 Irrigated in early season of growth

Total number of bolls	Weight per boll, gms	Length of lint, mm	Number of seeds per boll	Per cent lint	Weight seed, gms	Weight of lint per seed, gms	Weight of lint per gram of seed gms
			1930				
81	5.36	22.8	27.7	37.3	0.121	0.072	0.595
95	5.07	22.9	23.5	37.7	0.134	0.081	0.604
176	6.12	21.9	28.0	38.6	0.134	0.084	0.627
47	7.32	24.7	31.2	35.9	0.150	0.084	0.560
100	7.10	25.9	28.5	35.1	0.162	0.087	0.537
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
499	6.11	23.3	27.5	37.2	0.140	0.083	0.593
			1931				
17	6.62	25.7	26.9	37.8	0.153	0.093	0.608
75	6.48	24.9	29.0	37.3	0.140	0.083	0.593
196	6.29	24.0	28.9	40.4	0.130	0.088	0.677
196	6.56	23.2	30.9	40.7	0.126	0.086	0.683
42	6.41	23.2	29.6	39.9	0.130	0.087	0.669
29	6.62	24.9	32.8	40.0	0.121	0.081	0.669
3	5.25	24.3	27.0	40.2	0.116	0.078	0.672
558	6.44	23.9	29.8	39.9	0.130	0.086	0.662
			1932				
129	6.59	27.8	28.3	34.4	0.153	0.080	0.523
226	5.92	27.8	28.1	35.8	0.135	0.076	0.563
236	5.58	25.2	28.8	37.3	0.122	0.072	0.590
24	6.40	23.6	32.4	37.6	0.123	0.974	0.602
21	5.53	25.9	29.1	36.4	0.120	0.069	0.575
636	5.93	26.6	28.6	36.2	0.133	0.075	0.564

contain long lint regardless of soil moisture conditions. Since such bolls usually occur high on the stalk, these results seemed to support the findings of Kearney. The data obtained in this study do not offer a definite explanation of this. It would appear that the plants are not placed under a stress for water at the time the lint is elongating. The lack of a water stress might be due to a low rate of evaporation during the fall when the bolls are completing their growth, or the need for water might not be so great because there are only a few bolls present. According to Barre, Armstrong, and Bennett, some fibers may continue their elongation until maturity of the bolls. Since conditions might be favorable for fiber elongation during the fall, the late bolls, which have a long growth period, might produce long lint.

The correlation between the length of lint and the moisture content of the soil, using the results from all the plats in all the years, was

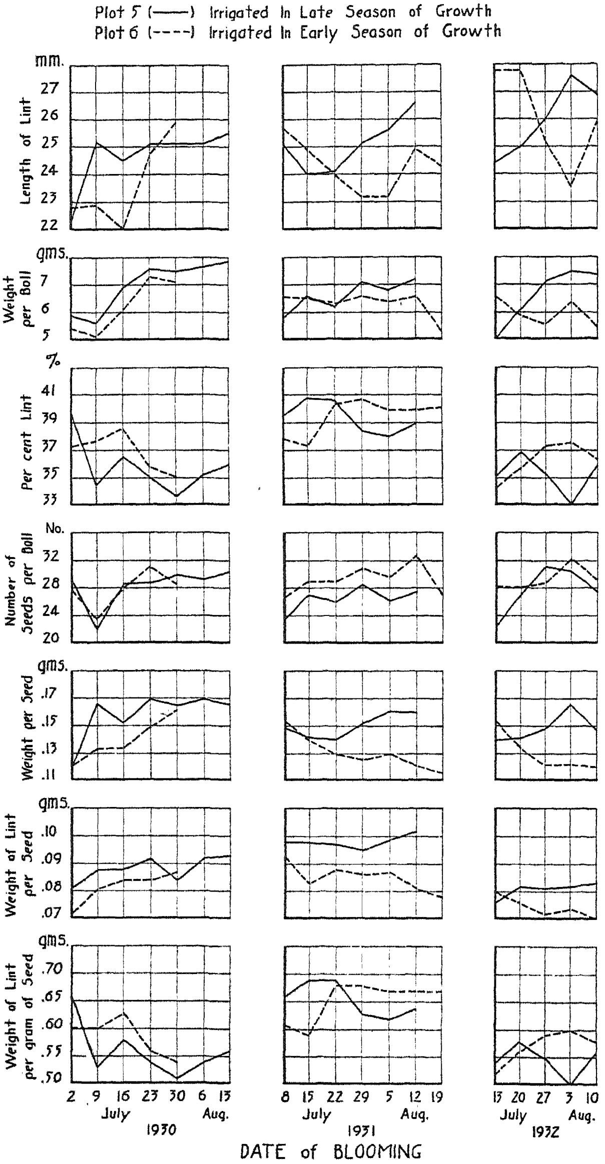

FIG. 4.—The average results by 7-day periods of determinations of the length of lint, weight per boll, percentage lint, number of seeds per boll, weight per seed, weight of lint per seed, and weight of lint per gram of seed made on cotton irrigated in the early season of growth and on that irrigated in the late season of growth in the 3 years of this study. The 7-day period was for 3 days before and 3 days after the date recorded. The dates recorded are the dates on which the blossoms opened that produced the bolls on which the determinations were made.

.678 ± .091. This relation is illustrated by Fig. 2. The relation is a linear one, but the point of origin is not 0. The critical period in the formation of the length of lint appears to be during the first 16 days after blossoming. This is shown by Fig. 5. It is seen that an irrigation affected the length of lint of bolls that were not over 16 days of age on the date of irrigation. Fig. 5 also shows the close relation that exists between the soil moisture and the length of lint.

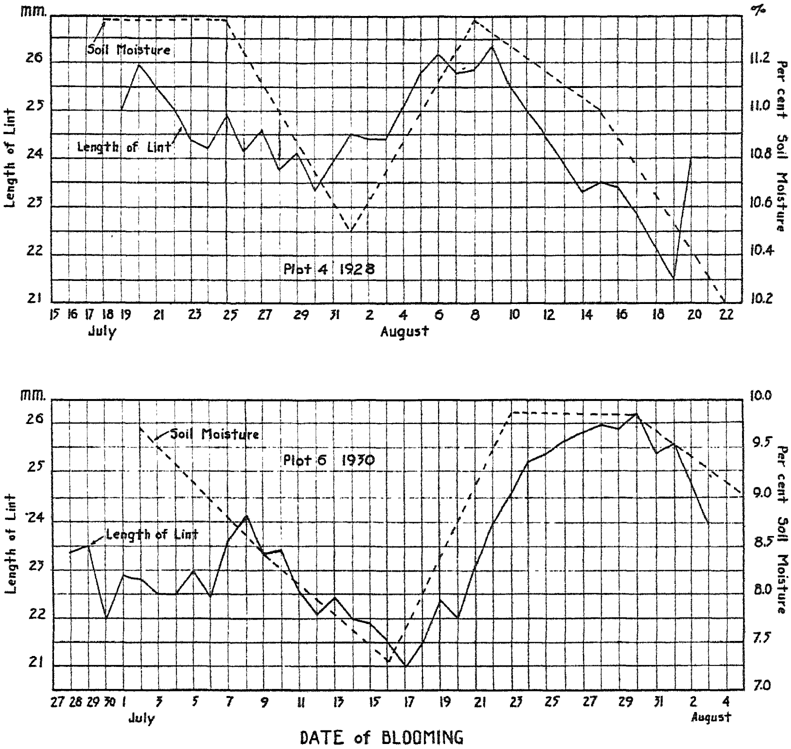

FIG. 5.—The length of lint by days and the percentage of soil moisture by 7-day periods for cotton irrigated each 8 weeks in 1928 and for that irrigated in the early and again in the late season of growth in 1930. The soil moisture is the average for 14 days after the date shown. In 1928, irrigation was on June 20 and August 15, and in 1930, it was on July 2 and July 30.

A deficiency in soil moisture always reduced the length of the lint if it occurred when the lint was growing in length. This reduction was not, however, in absolute proportion to the reduction in soil moisture nor was the increase in length from addition of water in proportion to the amount added. There appears to be a certain minimum and maximum length of lint for a variety. By reducing the moisture sufficiently the length would be decreased until this minimum is reached. Further reduction did not decrease the length, which indicates that a stress great enough to reduce it below this minimum must be so great as to cause the immature boll to be shed. Additions of water would increase the length of lint up to the maximum but further increase in the moisture would not have any effect. The difference between the minimum and maximum is approximately 3 mm or ⅛ of an inch for the strain of cotton used in this experiment. Greater differences than this occurred on some dates. For example, on August 19, 1928, the lint on plat 1 averaged 27 mm in length, while that on plat 4 averaged 21.5 mm. This is a difference of 5.5 mm, but it is based on the measurement of a few bolls and therefore represents only a small portion of the entire lint produced on these two plats.

A deficiency in soil moisture at any time during the period of the first 16 days after a blossom appears will shorten the length of lint produced by the resulting boll. The longer the duration of this deficiency the greater will be the reduction in the length of lint until the minimum is reached. This would indicate that most of the fibers either have practically completed their elongating shortly after the boll is 16 days old or that elongation after that date is not affected by soil moisture conditions. Balls reports that in Egyptian cotton the growth period is for 23 days. Barre, Armstrong, and Bennett state that it is for 30 days or more. The results here seem to agree more closely with those of Balls.

Barre, Armstrong, and Bennett found that some of the fibers practically cease to elongate by the time the boll is 30 days old, while other fibers continue to elongate until the boll reaches maturity. If this view is correct, then a shortage in moisture during any time before the boll is mature should tend to make some fibers short and, therefore, produce an ununiform staple. Consequently, it seems very unlikely that it will ever be possible to breed a variety with a uniform staple when grown under normal field conditions. Furthermore, it will be possible to produce a bale of uniform cotton only under very favorable conditions or by careful irrigation, because otherwise some of the bolls will likely be exposed to adverse conditions at some time during their development and have the fiber length reduced. It is probable that a great deal of the present non-uniformity of fiber length in individual bales of cotton is due to environmental variations under which the various bolls grew.

Balls concluded that the soil moisture affected the length of lint, a longer lint being produced when the soil had more moisture. Parsons found the same thing, but Burd reports the opposite to be true. The results of this experiment agree with those of Balls and Parsons. Burd's results may be explained by Balls' view that a rise in the water table would suffocate part of the root system and decrease the length of lint formed.

The results reported offer an explanation of why there is so much short staple cotton in some years. In a dry year the varieties which ordinarily produce a staple of ⅞ inch produce one that is less than ⅞ inch in length. Cotton shorter than ⅞ inch is not tenderable on future contracts and the trade accepts it only at a discount. Therefore, the farmer and the plant breeder are very much interested in the minimum staple that a variety will produce under adverse conditions. A variety should be selected that produces a staple of at least 1 inch in length in favorable seasons so that in dry seasons the staple will be at least 7/8 inch in length.

STUDIES OF CHARACTERS OTHER THAN LENGTH OF LINT

Influence of soil type.—The type of soil did not affect any of the characters studied, as shown by Fig. 1. The average weight per boll was not consistently larger for either soil type. The percentage of lint was the same for the two types of soil used, the maximum difference for any one year being only 1%. The cotton on the soil types used showed no significant difference in number of seed per boll, weight per seed, weight of lint per seed, or lint weight per unit weight of seed.

Influence of temperature, humidity, and evaporation.—The data obtained in this study are shown in Fig. 2. It is evident that under the conditions of this investigation the temperature, humidity, and rate of evaporation did not affect any of the characters studied.

Influence of soil moisture on weight of boll.—The boll weight (weight of lint plus weight of seed) was influenced by the soil moisture conditions under which the plant grew. The data illustrating this are shown in Fig. 3. The average weight per boll produced on plat 1, which was irrigated each week, was always greater than that on plat 4, which was irrigated but once in 8 weeks. The differences were 1.15, 0.62, 1.85, 1.39, and 1.81 grams, respectively, for the years 1928 to 1932, inclusive. As an average for the 5 years the bolls from plat 1 were 22% heavier than those from plat 4. It would require, on the average, 73 bolls from plat 4 to weigh a pound and only 60 from plat 1.

A detailed study of the data indicates that the critical period determining the weight of the boll is a long one and that any adverse condition during this period may have some effect on the weight of boll.

The reduction in weight of bolls by a deficiency in soil moisture was due to a lessening of the weight of the seed and of the lint rather than to a reduction in number of seed. The weight per boll is the resultant of the number of seed, weight per seed, and weight of lint. The weight of the lint and seed is determined over a period of 6 to 7 weeks; consequently, there is not a sharp break in the curve for either of these weights when the moisture is deficient over a short period and it follows that the boll weight would show the same results. Thus, any shortage of moisture should reduce the weight per boll, but it must act over a long period if this reduction is appreciable.

Influence of soil moisture on percentage of lint.—That the soil moisture had a very noticeable effect on the percentage of lint is evident in Fig. 3. The lint percentage was increased by a shortage of water. Plat 1 produced cotton with a lower percentage of lint each year than did plat 4. In 1929, 1 inch of water each week was not sufficient to keep the moisture content of the soil high enough on plat 1 to prevent a shortage and during the latter part of the season the percentage of lint was high. The percentage of lint on this plat increased rapidly after July 17 and the average for the year was only slightly lower than on plat 4. On plat 5, which was dry in the early season, the lint percentage was higher at this time than on plat 6, which was wet in the early season. During the latter half of the season the reverse was true.

The period during which a shortage of water increases the percentage of lint is from the date of blooming until the boll is 6 weeks old. After a boll is 6 weeks old there apparently is little if any effect on the lint percentage, but at any time prior to this age a drouthy condition will cause an increase in it.

The plats under drouthy conditions always produced the largest percentage of lint. These results are in contrast with Balls' view that favorable moisture conditions increase the lint percentage. Balls attributes an increase in the lint percentage to an increase in the number of fibers per seed and concludes that favorable moisture conditions on the date of blooming will result in a large percentage of lint. If Balls' view that the lint percentage is increased by favorable moisture conditions on the date of blossoming by increasing the number of fibers per seed is correct, then the weight of lint per unit weight of seed should be increased under these conditions. The results of this investigation, however, show that this does not happen. It seems, therefore, that the percentage of lint is determined by some factor other than moisture conditions on the date of blossoming. It appears that a decrease in seed weight greater than the corresponding decrease in lint weight is of more importance in determining lint percentage than is the increase in number of fibers per seed. The weight per seed is influenced more by the moisture conditions after the date of blossoming than by those prevailing on that date. Therefore, the percentage of lint is determined by moisture conditions after the date of blossoming rather than by those on that date, and furthermore, favorable moisture conditions decrease rather than increase the percentage of lint.

Influence of soil moisture on number of seed per boll.—There is no very definite relation between the soil moisture and the number of seed per boll. There is a tendency for the number of seed to be greater under moist conditions, but this is not always true. The results are illustrated in Fig. 3. It is probable that this character is independent of environment or was influenced by some factor not considered in this study.

Influence of soil moisture on weight per seed.—It may be noted in Fig. 3 that the weight of the seed was reduced by a shortage in the moisture of the soil. Cotton on plat 4 always produced lighter seed than that on plat 1. This relation is further shown by the results on plats 5 and 6 in 1931 and 1932 (Fig. 4). Plat 6 produced heavy seed early in the season and light seed late in the season. The opposite was true on plat 5.

The weight of the seed is determined over a long period extending from the date of blooming to nearly maturity, or approximately 6 weeks. Thus, any adverse moisture condition during this period would reduce the weight to some extent, and the longer the duration of the adverse condition the greater would be the reduction in weight.

Influence of soil moisture on weight of lint per seed.—The weight of lint per seed is reduced by a shortage of soil moisture. Plat 1 had a greater weight of lint per seed than did plat 4. The results of this study are shown in Fig. 3. The weight of lint per seed is determined by conditions extending over a long period. This period extends from date of blooming almost to maturity, or approximately 6 weeks.

The lint index (weight of lint per seed x 100) is increased by favorable moisture conditions and decreased by unfavorable ones. The same thing is true for weight of seed. Therefore, if a plant breeder selects on the basis of lint index, he will select for heavy seed that grew under favorable conditions and will likely have a low percentage of lint. On the other hand, if selection is on the basis of percentage of lint he will select for light seed that grew under unfavorable conditions and have a low lint index.

A large lint index is likely to be associated with a long staple and a low percentage of lint because conditions favorable to one are likely to favor the other. It is possible to have a long lint with a high percentage of lint by having moisture conditions favorable the first 3 weeks after blossoming and unfavorable the last 3 weeks. The lint index is affected more by the environment than is the percentage of lint.

Influence of soil moisture on weight of lint per unit weight of seed.—It is evident from Fig. 3 that soil moisture had an important effect on this character since plat 4 produced cotton with a higher unit weight of lint than did plat 1. Thus, the weight of lint per unit weight of seed is increased by drouthy conditions and decreased by moist ones.

A deficiency in soil moisture reduced the weight of lint per seed and the weight per seed. The weight per seed was reduced proportionately more than was the weight of lint per seed and therefore resulted in increasing the weight of lint per unit weight of seed.

SUMMARY

Studies were made to determine the influence of soil type, climatic conditions, and soil moisture on the development of lint and seed in cotton. Plants were grown in two very different types of soils in large galvanized iron cans to study the influence of soil type. For studying climatic and soil moisture responses plants were grown in the field, protected against rainfall, and irrigated at different intervals. Determinations were made on each boll for length of lint, weight of boll, number of seeds, weight per seed, weight of lint per seed, weight of lint per unit weight of seed, and percentage of lint.

Soil type did not affect any of the characters studied. Cotton grown in soil from the Mississippi Delta produced lint and seed which were in all respects like that grown in Norfolk sandy loam soil from Alabama.

Temperature, humidity, and evaporation had no measurable influence on the characters of seed cotton. Apparently cotton can tolerate the extremes of any of these encountered during this test without being adversely affected.

The amount of available moisture in the soil was the only factor studied which influenced the development of lint and seed in cotton. The influence of soil moisture may be briefly summarized as follows:

1. The length of lint was markedly affected by the amount of soil moisture. A low moisture content caused a short lint to be formed. The critical period in the elongation of lint was for approximately 16 days, beginning on the date of blossoming. It was possible to reduce the length of lint at least 3 mm (1/8 inch) by reducing the soil moisture to a critical point. There appeared to be a certain minimum and maximum length of lint for this strain of cotton.

2. The weight per boll, weight per seed, weight of lint per seed, and lint index were reduced by a lack of soil moisture. The critical period in determining these characters extended from 1 to 42 days after blossoming.

3. The percentage of lint and the weight of lint per unit weight of seed were increased by a deficiency in soil moisture. The period during which the lint percentage and the weight of lint per unit weight of seed were determined extended 1 to 42 days after blossoming. The percentage of lint varied less with soil moisture changes than did the lint index.

4. The number of seed per boll was not markedly dependent on the environmental conditions. There was a tendency for the number to be reduced by extremely drouthy conditions. A heavy boll was largely due to an increase in the weight per seed and weight of lint per seed.

5. Favorable soil moisture conditions produced heavy bolls with a long lint, heavy seed, large lint index, and low percentage of lint.

LITERATURE CITED

1. Balls, W. L. The development and properties of raw cotton. London: A. & C. Black, Ltd. 1915.
2. Barre, H. W., Armstrong, G. M., and Bennett, C. C. A study of the length and structure of cotton fibers. S. Car. Exp. Sta., 44th Ann. Rpt. 1931.
3. Burd, L. H. Cotton in St. Vincent. Trop. Agr., 2: 79–81. 1925.
4. ————. Reports on the research work carried out at the Cotton Experiment Station, St. Vincent, West Indies. Emp. Cotton Growing Rev., 2: 225–236. 1925.
5. Funchess, M. J. The weather has a lot to do with fixing the length of cotton staple. Progressive Farmer, 46: 20. 1931.
6. Harland, S. C. The importance of cotton breeding to the spinner. Textile Recorder, 45: 87. 1927.
7. Hawkins, R. S., and Serviss, George H. Development of cotton fibers in the Pima and Acala varieties. Jour. Agr. Res., 40: 1017–1029. 1930.
8. Kearney, T. H., and Harrison, G. J. Length of cotton fiber from bolls at different heights on the plants. Jour. Agr. Res., 28: 563–565. 1924.
9. Ludwig, C. A. Some effects of late defoliation in cotton. S. Car. Exp. Sta. Bul. 238. 1927.
10. Veihmeyer, F. J., and Hendrickson, A. H. Soil moisture conditions in relation to plant growth. Plant Phys., 2: 71–82. 1927.
11. ————. Some factors affecting the irrigation requirements of deciduous orchards. Hilgardia, 2: 125–287. 1927.
12. Youngblood, B. Relation of soil fertility to the quality of cotton. Proc. 30th Ann. Conv. Assoc. Southern Agr. Workers, 106–109. 1929.

OUTLYING EXPERIMENT FIELDS AS A MEANS OF DETERMINING THE FERTILITY OF DIFFERENT SOIL TYPES[1]

F. L. DULEY[2]

It has long been recognized that information secured at the central experiment station will not apply directly to the various conditions in different parts of a state. To supply this more or less local need several methods have been employed. In some states substations have been established. These are usually few in number and cannot represent many soil types. The work done at these substations is, however, carefully conducted under the direct supervision of well-trained men. It is also extensive enough to include a wide range of experiments.

Small permanent fields have been used in some states. In many cases, these have been donated to the experiment stations. They are usually too small to be called substations and are seldom representative of a single soil type. They have the advantage of permanency and have usually been well managed.

In other states information on specific soil types has been secured by the use of temporary experimental fields. These fields have usually been leased by the station for a period of 5 to 15 years and the farmer owning the land has been employed to care for the crops under the supervision of a technically trained man.

In order to apply the results of field experiments throughout the extent of a given soil type, it is necessary to assume a reasonable uniformity of the type involved. Some types are normally more uniform than others. In addition to this they may also remain more uniform. An example of this difference in conditions may be found in a comparison of the Putnam silt loam, a level prairie soil, with the Shelby loam, a glacial drift soil. The Putnam is not only more uniform than the Shelby under normal conditions, but it is not disturbed to the same extent by erosion. There are, however, certain groups of soil types that respond to the same treatments and after tests have thoroughly demonstrated this fact, they may be considered together so far as some particular treatments are concerned. The points of difference that exist between such types may be kept in mind whenever recommendations for treatments are being made. Lyon[3] has already presented these points.

VARIATION IN RESPONSE TO TREATMENTS

Some types of soil are so deficient in certain elements that even the most crude test may be sufficient to bring out the need for a given treatment. Such tests are often made by farmers by shutting off

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[1] Contribution No. 220, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Also presented before the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication February 6, 1933.

[2] Professor of Soils.

[3] LYON, T. L. Is the soil type homogenous with respect to its fertilizer needs? Jour. Amer. Soc. Agron., 24: 58–71. 1931.

the fertilizer drill for one round when seeding grain. Demonstration plats placed by county agents, vocational agricultural teachers, and others may be used to accumulate information regarding the needs of certain soils. The difficulty with such tests is usually the fact that the results are not carefully correlated with the soil type, which in many cases may not be known. Failure to make such correlations has greatly limited the value of a tremendous number of such field tests. The use of semi-permanent outlying experiment fields away from the central station has certain distinct advantages over short-time and miscellaneous tests for determining the needs of a given soil type. In the first place such experiment fields are usually chosen with considerable care in order to locate them on representative areas of the soil type to be studied and on land that has not been greatly affected by previous soil treatments. Furthermore, the tests are in most cases carried on for a sufficient number of years to give dependable results. The fields are extensive enough to permit a considerable range of treatments and enough duplication to insure a reasonable degree of accuracy. Although it has seldom been done, comparisons of different rotations may be made on such fields. This type of experiment necessarily requires a considerable amount of uniform land for its location and several years duration for its completion. Such tests cannot be carried out in cooperation with farmers. The outlying field is therefore a suitable place for tests of this kind, particularly if the rotation cycles are not too long. This precaution is necessary because in most cases it is not possible to operate outlying fields for more than 10 to 15 years where the station does not own the land. Rotations or other experiments requiring more time should be carried out at the main station or at substations.

DETERMINING MAJOR REQUIREMENTS

With nearly every soil there is some soil treatment that may give good returns under one set of conditions or on one crop and not on another. The fact must also be recognized that there is sufficient range in soil characteristics within any type to bring about at least minor differences in the response to soil treatments. Very carefully conducted field experiments are required to establish these minor differences with certainty. Outlying experiment fields have usually been considered to have served their purpose if they establish definitely the major requirements of different soil types. The results from 17 Missouri experiment fields[4] located on 12 soil types showed an increase in the yield of red clover from the use of lime varying from 110 to 2,266 pounds of hay per acre. That these soil types in general responded in approximately the same order has been demonstrated by later practice.

These soils also showed a response to phosphates varying from 225 to 2,207 pounds of red clover hay per acre. The need for phosphorus, however, was not very well correlated with the need for lime. More of the soils gave high returns for phosphorus than for lime and some of the soils that showed little need for lime gave good returns for phosphate. The accuracy of these experimental results with phosphorus has likewise been amply demonstrated by the use of phosphatic fertilizers on farms on these various soil types.

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[4] Duley, F. L., and Miller, M. F. Soils experiment fields of Missouri. Mo. Agr. Exp. Sta. Bul. 238. 1926.

The Iowa station[5] has found from average results on 13 fields that lime and phosphate are desirable for Grundy silt loam. Calculations made on these data show that lime was used on nine fields at a distinct profit, while on two fields it was of doubtful value and on two fields it was used at a loss. Superphosphate also showed some advantage on the average, but when the individual fields are studied, five of them could be considered as showing a good profit for phosphate, three were doubtful, and five would show a loss at what might be considered normal prices for products.

The Illinois station[6] showed lime to be profitable on the Grundy soils, but the return varied quite widely on the different fields. The average annual value of crop increases due to liming on the Aledo, Carthage, Hartsburg, and Lebanon fields varied from $3.25 on the Hartsburg field to $8.32 on the Lebanon field as an average of the livestock and grain systems of management. On three fields of Gray silt loam on tight clay the return from lime varied from $6.15 on the Oblong field to $8.66 on the Newton field. The Toledo field was intermediate. The returns were a little more consistent than on the Grundy soils and the increase was greater.

However, both of these soils gave good returns for the use of lime. The returns have been approximately the same on the two types under the grain farming system, but considerably more on the Gray silt loam than for the Grundy soils on manured land.

Neither of these soils has given a marked increase for phosphate. A comparison might be made with the results on the Grundy series in other states. The results in Iowa showed some increase for phosphate, but the increase was not consistent on all fields. In Missouri, on one field, somewhat greater increases were obtained for phosphate than is shown by the Illinois results. A part of these differences possibly may be due to the fact that superphosphates and bone meal were used in Missouri while rock phosphate was used in Illinois. In Iowa both phosphates were used and the greatest increases were obtained from the superphosphate on this type of soil.

DEMONSTRATIONAL VALUE OF OUTLYING FIELDS

An additional value of outlying fields that should not be overlooked is their use for demonstrational purposes. The only real excuse for experiments of this type is that the results may eventually be reflected in the farm practices of a community and particularly on farms lying on the soil type involved, or on closely related soil types. County agents and other extension agencies can do much to give publicity to the station results. Annual or at least occasional meetings should be held on the fields when there is good opportunity for farmers to observe the effects of soil treatments. Care should be exercised, however, that not alone the big differences for the season be given special attention at such meetings, but the general trend of the results based on as many years data as possible should be clearly pointed out. This demonstrational value would be one of the outstanding reasons for using outlying fields, even though we had some other methods for determining the needs of the soil.

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[5] Stevenson, W. H., *et al.* A soil management program for Grundy silt loam. Iowa Agr. Exp. Sta. Bul. 280: 165–184. 1931.

[6] Bauer, F. C. Crop yields from Illinois soil experiment fields. Ill. Agr. Exp. Sta. Bul. 382. 1932.

SHORTCOMINGS OF OUTLYING FIELDS

There are several sources of error that have been common on experiment fields of this sort. In the first place, in the selection of a location for such fields, it is necessary to take into consideration the qualifications of the farmer who is to operate the field. A careless operator may cause failure to get results on the most carefully selected field. Furthermore, the reputation of the field in a locality may depend as much on the popularity of the cooperator as upon the quality of the work accomplished. In attempting to select a good cooperator, some sacrifice must often be made in the selection of the soil for it is seldom possible to find the most desirable cooperator located on the most representative part of a soil type. Furthermore, many of the most desirable cooperators have given their soil such heavy treatments of manure, lime, or fertilizers that it can no longer be considered representative of the original soil type. The history of the field should be given very careful consideration in the selection of an experiment field. It has been shown that some of the Illinois fields have as many as nine different types or phases of types represented. Many of the fields have three or four types. There is no doubt that somewhat similar conditions exist on many fields in other states, but in most cases they have not been so carefully mapped.

Another difficulty has been the fact that in most states a given soil type has been represented by only one or at best by only a few fields. This has led to the results obtained on one field being applied over all parts of this type, whereas the results in Illinois and Iowa show that if a greater number of fields are placed on a given type considerable variation in the results will usually be obtained.

Another point on which the work of the outlying fields in the past might be criticized is the fact that almost the entire effort has been placed on the testing of different fertilizer and manure treatments. On several fields recently started by the Kansas Station the question of cropping systems best suited to that soil and climatic condition is given a very important place along with the fertilizer tests.

In connection with this question it must be admitted that when soil experiment fields are used it becomes necessary to apply the results of relatively accurate tests made at one location over a wide area, much of which may have considerably different requirements than the soil where the tests were made. In the case of laboratory and greenhouse tests or short-time trials by farmers the results of perhaps less accurate determinations are applied to very limited areas. Both methods of testing may therefore have a place in determining the need of different soil types. Perhaps the most logical use of the two methods would be for the general crops and fertilizer needs of a soil type to be determined by outlying fields and then this should be supplemented by other tests on individual farms or even fields, as well as by laboratory tests to ascertain more definitely the specific needs of small areas.

THE INFLUENCE OF CROPPING SYSTEM AND FERTILIZATION ON THE REACTION OF SASSAFRAS SILT LOAM SOIL[1]

Henry C. Harris[2]

The purpose of this investigation was to make a comparison of the pH values of soil from certain of the fertility plats which were laid out on the Delaware Agricultural Experiment Farm in 1908. It was hoped that by comparing plats on which different cropping systems have been grown some indication as to the influence of the cropping system on the pH value of the soil might be secured. Incidentally, since various plats have had different fertilizer and manure treatments, it was thought that the results secured would indicate also the effect of fertilization on the reaction of this soil under field conditions.

HISTORICAL

Blocks B and F were selected for the comparisons because these blocks are adjacent, on the same type of soil (Sassafras silt loam), and because different cropping systems have been used on them. So far as is known the soil on both blocks is as nearly alike as could be conveniently secured.

Block B contains 16 one-tenth acre plats. Each plat of this block is divided into two equal parts, one half having been limed, the other not. All the limed sections received hydrated lime at the rate of 2,000 pounds per acre in 1908 and 1916, while 1,500 pounds per acre were used in 1912, 1920, and 1924. This makes a total of 8,500 pounds per acre applied before any soil samples were taken.

The limed and unlimed parts of each plat have always received the same fertilizer and manure treatments. The total amounts are given in Table 1. Details of the treatments have been published elsewhere.[3]

The rotation used on this block from 1908 to 1912 was corn, oats, wheat, and timothy and clover, but in 1912 this was changed to corn, soybeans, wheat, and timothy and clover. The latter rotation has been continued to the present.

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[1] Contribution from the Department of Agronomy, University of Delaware Agricultural Experiment Station, Newark, Del. Published with the approval of the Director of the Station. Received for publication February 16, 1933.

[2] Assistant Professor.

[3] Schuster, George L. Fifteen years of field experiments with manure, fertilizers, and lime on Sassafras silt loam soil. Del. Agr. Exp. Sta. Bul. 137 (Tech. Bul. 4.) 1924.

——— and Phillips, C. E. Fertility rotation experiments. Del. Agr. Exp. Sta. Bul. 162: 12–14. 1929.

There are eight one-tenth acre plats on block F. Each plat of this block also has a limed and an unlimed half. Hydrated lime was applied to the limed halves at the rate of 2,000 pounds per acre in 1908, 1913, and 1915, while the rate was 1,500 pounds per acre in 1919 and 1923, making a total of 9,000 pounds per acre applied up to the time the soil samples were taken.

The limed and unlimed halves of the plats on block F, too, have always received the same fertilizer and manure applications. The details of the treatments have been published and will not be repeated.[4] A summary is given in Table 2.

This block has been in corn continuously since the experiment was begun in 1908. During the period of 1908–1923, inclusive, no cover crops were grown except on plats 7 and 8 where crimson clover was planted. However, the clover never grew very successfully on these plats. Since 1923 a cover crop of rye and vetch has been grown on the entire block.

SAMPLES

Samples of soil were taken from the limed and unlimed halves of both blocks at as nearly the same time as was possible. Three sets were taken, the first in the fall of 1928, the second in the fall of 1931, and the third in the late summer of 1932. In 1932 this was done by driving a 1 5/8-inch iron pipe down 6⅔ inches and taking out a core of soil. Twenty of these cores were thoroughly mixed for a sample. The 20 cores were distributed over the area in four rows of five each. One row was placed 6 feet from one edge of the plat, another row 6 feet from the other edge of the plat, and the two remaining rows equal distances between those rows. The cores in a row were spaced as nearly equal distances apart as could be paced. The end cores of a row were placed 6 feet from the edge of the area being sampled. This gave a border of 6 feet all around each half plat where no cores were taken, the idea being to eliminate any error due to the transfer of soil by plowing. In 1928 and 1931 the samples were taken with a soil auger. Ten borings to a depth of 6⅔ inches were thoroughly mixed and used for a sample. The distribution of the borings was similar to that given in connection with the soil cores.

The samples secured as described above were put through a 2-mm sieve and the coarse gravel discarded.

pH DETERMINATIONS

The pH values were determined potentiometrically, using a hydrogen electrode. In 1928 a suspension consisting of 5 grams of air-dry soil made up to 50 cc with distilled water was used for the determinations, but in 1931 and 1932 the determinations were made on 20 grams of field-moist soil in 40 cc of distilled water. The 1932 samples were taken at a very dry time, and apparently a comparatively small amount of moisture was present in the field-moist soil that year.

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[4] SCHUSTER, GEORGE L. Corn production experiments in Delaware. Del. Agr. Exp. Sta. Bul. 146: 8–9. 1926.

DISCUSSION OF RESULTS

The results are given in Tables 1 and 2. As can be seen from these tables, there are distributed among the plats on blocks B and F, check plats which have had no fertilizers or manure. The hydrogen-ion concentration of the soil from the two blocks at the beginning of the experiments is not known, but even in that case it would seem that the influence of the fertilizers and the manure on the reaction of this soil under field conditions would be shown moderately well by the deviations in pH value from that of the untreated checks.

TABLE 1.—*The pH of soil from block B.*

Plat No.	Treatment, 1908–32, lbs. per acre*	Limed			Unlimed		
		1928	1931	1932	1928	1931	1932
1	No treatment	6.82	7.38	6.91	5.63	5.74	5.75
2	1,600 lbs. nitrate soda, 75 lbs. dried blood	6.53	7.28	6.88	5.52	5.84	5.86
3	3,900 lbs. superphosphate	6.87	7.40	6.70	5.54	5.72	5.67
4	1,335 lbs. muriate of potash	6.54	7.22	6.89	5.80	5.59	5.60
5	1,525 lbs. nitrate of soda, 300 lbs. fish scrap 3,776 lbs. superphosphate	6.59	7.28	6.77	5.72	5.76	5.79
6	No treatment	6.57	7.14	6.93	5.73	5.71	5.72
7	3,900 lbs. superphosphate, 1,335 lbs. muriate of potash	6.37	7.08	6.84	5.61	5.71	5.82
8	1,675 lbs. nitrate of soda, 1,335 lbs. muriate of potash	6.97	6.98	6.75	5.51	6.03	5.96
9	1,599 lbs. nitrate of soda, 75 lbs. dried blood 3,900 lbs. superphosphate, 1,335 lbs. muriate of potash 3,150 lbs. nitrate of soda, 100 lbs. dried blood	6.38	6.98	6.80	5.42	5.59	5.79
10	7,300 lbs. superphosphate, 2,550 lbs. muriate of potash	6.30	6.84	6.65	5.44	5.62	5.74
11	No treatment	6.42	7.20	6.75	5.48	5.79	5.67
12	400 lbs. nitrate of soda, 100 lbs. dried blood 50 lbs. ammonium sulfate, 1900 lbs. superphosphate, 1,335 lbs. muriate of potash, 1,800 lbs. basic slag	6.53	7.17	6.87	5.43	5.84	5.79
13	176 lbs. calcium cyanamid, 750 lbs. superphosphate, 3,000 lbs. rock phosphate, 915 lbs. muriate of potash	6.48	7.12	6.72	5.56	5.72	5.93
14	750 lbs. superphosphate, 65 tons farm mnaure	6.62	6.98	6.65	5.56	5.78	5.69
15	130 tons farm manure	6.88	6.96	6.77	5.48	5.69	5.71
16	No treatment	6.88	6.81	6.63	5.48	5.66	5.67

*Basic slag and rock phosphate were discontinued in 1925. Dried blood, ammonium sulfate, and calcium cyanamid have been applied since 1925.

On the limed halves of the blocks the maximum deviation from the pH value of the nearest check plat was 0.4. This occurred on plat 8, block B, in 1928. The other 2 years that plat showed differences less than 0.2 pH. In general, on the limed parts of the blocks, the pH value of the treated plats did not vary from that of the nearest check by more than about 0.2. In the few cases where larger differences were secured, the results were not consistently that way for all 3 years.

TABLE 2.—*The pH of soil from block F.*

Plat No.	Treatment, 1908–32, lbs. per acre*	Limed			Unlimed		
		1928	1931	1932	1928	1931	1932
1	190 tons farm manure	7.84	8.14	7.71	6.06	6.77	6.53
2	95 tons farm manure, 1,200 lbs. superphosphate	7.96	8.19	7.92	5.97	6.54	6.49
3	No treatment	7.73	8.30	8.00	6.05	6.30	5.97
4	2,245 lbs. sodium nitrate, 120 lbs. dried blood, 5,450 lbs. superphosphate, 1,563 lbs. muriate of potash	7.69	8.30	7.90	5.83	6.06	5.79
5	4,410 lbs. sodium nitrate, 160 lbs. dried blood, 10,100 lbs. superphosphate, 2,934 lbs. muriate of potash	7.81	8.14	7.88	6.24	6.42	5.88
6	No treatment	7.91	8.30	8.09	5.88	6.11	5.89
7	80 lbs. sodium nitrate, 80 lbs. dried blood, 80 lbs. sulfate of ammonia, 5,450 lbs. superphosphate, 1,563 lbs. muriate of potash	7.58	8.12	7.88	6.02	5.75	5.62
8	1,200 lbs. superphosphate, 288 lbs. muriate of potash	7.88	8.14	7.81	5.88	6.23	5.98

*Dried blood and sulfate of ammonia applied since 1925; superphosphate applied to plat 2 since 1925.

In regard to the unlimed parts of the plats, the greatest deviation from the pH value of the nearest check plat was 0.56. This occurred on plat 1, block F, in 1932. Generally the treated plats on the unlimed halves did not differ in reaction from the nearest checks by more than 0.25 pH unit. Where larger variations were secured they were never consistently that way through all 3 years.

In view of the small differences in pH value of the treated and untreated plats on both the limed and unlimed parts of these blocks, it appears that neither farm manure nor the nitrogen, phosphorus, or potash fertilizers applied to these plats have had any appreciable influence on the reaction of this soil.

Generally it has been found that fertilizers influence the reaction of the soil, and the fact that the results secured here suggest something different for this soil is probably due to local conditions and the particular combinations of fertilizers used in these experiments. For that reason the results are recognized as having only local application.

Blocks B and F have had similar fertilizer treatments, and the applications of lime have been almost identical. The total amount of hydrated lime applied since the experiments were begun in 1908 to the limed half of both blocks is 8,500 and 9,000 pounds per acre, respectively. The last application on block B was 1,500 pounds per acre in 1924, while the last application on block F was at the same rate in 1923. Even though the treatments are much alike there is considerable difference in the reaction of the soil on the two blocks, especially on the limed portions. The amount of this difference is shown by the fact that the range in reaction of the limed plats of block B in 1928 was from pH 6.30 to 6.97, while that for the limed portion of block F for the same year was from 7.58 to 7.96. The pH values for the four check plats on the limed half of block B during 1928 were 6.82, 6.57, 6.42, and 6.88, while that for the two check plats on the limed half of block F for the same year were 7.73 and 7.91. Samples of soil from the limed portions of block F and block B were wet with distilled water, and after air bubbles had been driven out of the soil, acid was applied. The samples from block F effervesced freely, showing that a considerable surplus of lime was being held in the soil in the carbonate form. The samples from block B did not effervesce. In 1928 the pH values for the unlimed halves of block B ranged from 5.42 to 5.80, while during the same year for the unlimed parts of block F they ranged from 5.88 to 6.24. The pH values for the check plats on the unlimed half of block B in 1928 were 5.63, 5.73, 5.48, and 5.48, while at the same time those for the same kind of plats on block F were 6.05 and 5.88. Thus we see that the pH values for block F are higher than for block B. On the limed halves the difference amounts to about one pH unit, while on the unlimed halves the difference is about three-tenths of a pH unit. The pH determinations for the other 2 years show similar differences.

If the reaction of the soil on blocks B and F was about the same when the fertility experiments were begun, the difference now found in the reaction of the two blocks would appear to be due to the type of cropping systems used on them, especially since the fertilizer treatments which were applied to this soil seem to have had little effect in that respect. Block F is in corn each year, while a rotation of corn, soybeans, wheat, and timothy and clover is grown on block B. In the case of continuous corn, conditions are not favorable for the largest yields, and thus less lime probably is removed through the crop. In the case of the rotation, the yields are usually larger, which is likely to result in the removal of more calcium. During the period of these experiments, plat 4 of block F and plat 9 of block B have had similar fertilizer treatments, and a comparison between these two plats should give a rough indication of the crop removal of lime by the two cropping systems. Published and unpublished data collected by the Department of Agronomy of the University of Delaware give the crop yields of these two plats with the exception of a few cases where the straw yields are not known. From these data the writer has estimated the amounts of crops removed from these two plats during the period under discussion, and by using the analysis given in Henry and Morrison's *Feeds and Feeding*, has calculated the pounds of CaO removed from each plat by the crops. This calculation indicates that 61.8% more CaO was used by the crops of the rotation than in the case of continuous corn. This difference in calcium removed very likely affects the pH value of the soil. Other factors which influence the reaction of the soil probably are affected by the type of rotation.

The pH value of the soil from the two blocks at the beginning of the experiments is not known, and that fact makes it impossible to draw a positive conclusion in regard to this point. However, the two blocks are adjacent, on the same kind of soil, and the circumstances surrounding the experiments would strongly suggest that the pH values were about the same at that time. For that reason the data secured are offered as circumstantial evidence indicating that the pH value of this soil has been influenced by the cropping system grown on the soil, especially where lime was applied. This type of evidence is advanced for the lack of positive proof in the present experiments or, so far as the writer knows, elsewhere.

SUMMARY

Long-time fertilizer and manure treatments, as applied to plats located on the Delaware Agricultural Experiment Farm, appear to have had no appreciable influence on the reaction of the soil. This is probably due to local conditions and the combinations used.

Tentative evidence is given indicating that the type of rotation grown on Sassafras silt loam soil influences the pH value of the soil.

THE REPLACEABLE POTASSIUM CONTENT COMPARED WITH FIELD RESPONSE TO POTASH FERTILIZATION OF SOME OKLAHOMA SOILS[1]

H. F. Murphy[2]

During recent years considerable experimental work has been done concerning the potash of the soil. The results as a rule have shown that in mineral soils, with but few exceptions, it is not a matter of potash deficiency so much as it is of availability. The total potassium content of soils usually ranges from 10,000 to over 60,000 pounds per 2,000,000 pounds of soil with the exception of peats, mucks, and some sandy soils, but the available supply may be limited even in those soils having the greater total supply. The soil's potash supply comes from the silicates, and as these are the most resistant soil compounds, the potash question resolves itself largely into one of availability.

Various methods have been used to determine or study the available supply with an idea of correlating this with fertilizer practice. Among the biological methods in more common use are the Neubauer seedling method (4)[3] and the soil plaque method (6). General plant ash analyses as well as stalk tests (2) have also been used.

The chemical methods which have been used are quite numerous. Many investigators have studied the water-soluble potash content of soils and others have made extensive studies of the displaced soil solution and artificial solutions (1, 3, 5) in order to determine the needs of plants for a potassium level, or to determine the ability of different soils to replenish the soil solution. This latter point is of fundamental importance, for a relatively low nutritive level if constantly maintained will produce good crops while a high quantity may not produce nearly as good a crop if the solid phase does not contribute to it sufficiently to maintain it above the critical level. There are cases where very little if any addition needs to be made to the potassium present in the soil solution at the beginning of the season in order to produce a particular crop, but as a general thing we must look to the solid phase to furnish a certain amount to the solution, and the rate at which it furnishes this is of vital importance to proper plant growth.

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[1] Contribution from the Department of Agronomy, Oklahoma Agricultural and Mechanical College, Stillwater, Okla. Received for publication February 20, 1933.

[2] Associate Professor of Soils.

[3] Reference by number is to "Literature Cited," p. 37.

It is not the purpose of this paper to enter into the question of the absorption of potassium by plants, but rather to present some data concerning the replaceable potassium content of soils and as nearly as possible correlate such data with crop response under field conditions.

During the last year the replaceable potassium content of several soil samples was determined by the neutral normal ammonium acetate method. These samples were collected or had been collected very largely from fields on which some fertilizer data were available. Unfortunately, some of the data were of such a nature as to give very little information as to potash response because the experiments were designed for other purposes. For most of the soils used it can be said generally that if they are in need of potash, a big response will also be secured from an application of phosphorus along with the potash. Perhaps it had better be stated that phosphorus is generally limiting plant growth in such soils more so than is potash. Nitrogen and organic matter are also low in a large number of the soils used in collecting these data.

Most of the samples used in this paper were secured from the eastern one-half of Oklahoma where the rainfall averages more than 30 inches annually. Not many samples were used from the western one-half of the state, because few fertilizer experiments in that section have been profitable and because rainfall and soil moisture are limiting factors more often than is lack of available plant food.

Besides the Oklahoma soils, determinations of the replaceable potassium content of some soils from other sections of the country were included where plant indications and other information furnished indicated potash deficiency or response to potash fertilization. The writer is greatly indebted to all those who contributed in this respect and also to other members of the department for field data used in determining response.

The soils were placed in groups according to their replaceable potassium content, and the divisions given in Table 1 appear to have some merit in classifying them in respect to crop response. The crops used in determining the response were chiefly corn, cotton, potatoes, sweet clover, and alfalfa. All crop data were from field results.

Group 1 included 29 samples. Of these, 23 showed response, no data were available for 5, and 1 gave no appreciable response. The soil showing no response was well supplied with organic matter and contained 58 ppm of replaceable potassium. The other soils in the group were low in organic matter. All of these soils responded to phosphorus fertilization. In order to get response to potash in most cases it was necessary to supply phosphorus as well. A complete fertilizer would generally be the most desirable fertilizer for the Oklahoma soils in this group. Four out-of-state samples were included and all of them were designated as being responsive to potash fertilization.

TABLE 1.—*Showing the amount of replaceable K and crop response.*

Group	No. of samples	Replaceable K in p.p.m.	Crop response
1	29	Under 60	Good response
2	21	60–79	Response in many cases
3	19	80–99	Doubtful
4	23	100–124	Very doubtful
5	52	125–199	No response ordinarily
6	32	Over 200	No response

Group 2 included 21 samples. It is unfortunate that there are few data available for this group. In only nine cases are sufficient data available to determine potash response and in each case some response is secured. A very large number of these soils are low in available phosphorus, and phosphorus fertilization usually pays on them.

Group 3 included 19 samples. The response in this group is doubtful in most cases; although on many of these the plants showed some characteristics indicative of potash deficiency to a certain degree.

Groups 4, 5, and 6 included 23, 52, and 32 samples, respectively. No response was secured from any of these soils. Many extensive fertilizer tests have been conducted on the soils in groups 4 and 5 with negative results so far as potash is concerned except in one or two cases. In no case has any response been secured from soils containing over 200 p. p. m. of replaceable potassium.

Many factors may modify crop response to any given nutrient. The Oklahoma soils used in the above groupings had a pH ranging from about 5.5 to 8.2 and a large number of them were deficient in phosphorus. The organic matter content was also generally low, especially in the lower groups or those responding to potash fertilization. Rainfall data show that the responsive soils received 30 inches or more rainfall annually. Many of the soils had been in cultivation for several years without receiving any fertilizer or manure and in many cases without ever having been planted to a legume crop. The virgin soils corresponding to the cropped soils were low, as a rule, particularly in phosphorus and organic matter compared to many soils and this has limited crop production in many cases.

It is of interest to note the replaceable potassium content of 17 paired representative cropped and virgin soil samples from various parts of Oklahoma. It included three soils from group 1, two from group 2, three from group 3, three from group 4, two from group 5, and four from group 6. The virgin soils ranged from 71.5 to 557 p. p. m., with an average of 199 p. p. m., while the cropped samples ranged from 35 to 556 p. p. m. and averaged 167 p. p. m. replaceable potassium. In four cases some gain occurred, while all others showed a loss. All four samples showing a gain were from the western one-half of the state. As a rule the soils from the western part of the state were considerably higher in replaceable potassium than those from the eastern part of the state.

In this connection the data from manured and unmanured wheat land are of interest. This land was broken from sod in 1892, and since 1898 manure has been applied to part of the area at the average rate of approximately 4 tons annually, the manure being applied every 4 years. The unmanured soil shows a replaceable potassium content of 111 p. p. m., while the manured soil shows 199 p. p. m. The average yield of wheat on the two areas has been approximately 20.9 bushels per acre for the manured and 12.3 bushels per acre for the unmanured soil.

These data would indicate that it is desirable to keep the soil well supplied with active organic matter not only for many other reasons but also as a means of increasing the replaceable and therefore available potassium in the soil.

SUMMARY

1. Oklahoma soils containing less than 60 p. p. m. of replaceable potassium generally respond to potash fertilization if other factors are favorable for plant growth.
2. Cropped soils contained less replaceable potassium than virgin soils.
3. The replaceable potassium content of a manured soil was much higher than the corresponding soil which had never received any manurial applications.

LITERATURE CITED

1. Bartholomew, R. P., and Janssen, George. The relation between concentrations of potassium in culture solutions and optimum plant growth. Soil Science, 27: 189–203. 1929.
2. Hoffer, G. N. Testing corn stalks chemically to aid in determining their plant food needs. Ind. Agr. Exp. Sta. Bul. 298. 1926.
3. Johnston, E. W., and Hoagland, D. R. Minimum potassium level required by tomato plants grown in water cultures. Soil Science, 27: 89–109. 1929.
4. Neubauer, H., and Schneider, W. Die Nährstoffaufnahme der Keimflanzen und ihre Anwendung auf die Bestimmung des Nährstoffgehalts der Böden. Ztschr. Pflanzenernahr. u. Düngung, 2:329–362. 1923.
5 Parker, F. W., and Pierre, W. H. The relation between the concentration of mineral elements in a culture medium and the absorption and utilization of those elements by plants. Soil Science, 25: 337–343. 1928.
6. Sackett, Walter G., and Stewart, Laura C. A bacteriological method for determining mineral soil deficiencies by use of the soil plaque. Colo. Agr. Exp. Sta. Bul. 375. 1931.

FRUITING CHARACTERS AND TIME AND COST OF PICKING COTTON VARIETIES[1]

G. A. Hale[2]

The qualities of cotton which affect its selling price and spinning value have received much attention from agronomists and economists during recent years. Little work, however, has been done on cotton varietal characters, other than yield, which affect cost of production. According to figures compiled from statistics published by the U. S. Dept. of Agriculture (2),[3] the cost of harvesting or picking and marketing cotton has been about one-fifth of the total cost of growing and marketing the crop in this country during the past 3 years. This harvesting and marketing cost (ginning not included) is the largest cost item in cotton production, and practically all of it is for labor used in hand-picking the seed cotton. The hand-picking factor is not only very important in the unit cost of production, but it also determines the amount a worker can produce, as harvesting is generally the limiting factor in individual output.

Cotton growers believe that cotton can be produced at a lower cost by the use of certain large-boll varieties, the seed cotton of which can be easily and quickly picked from the open burs, than by the use of small-boll and other varieties which require more time to pick. Even when the harvesting is done by hired help for a stipulated amount per pound of seed cotton, picking quality, or the amount a worker can pick in a certain time, is important to the owner of the crop as it is sometimes difficult to get certain varieties picked because of the small amount a worker can harvest in a day.

According to Watkins (3), the introduction into Mississippi during the early part of the 19th century of the large-boll Mexican variety of cotton was considered second in importance to the invention of the saw gin. Prior to that time only small-boll varieties were grown and the average day's picking was only 75 to 100 pounds of seed cotton, while a picker could harvest 150 or more pounds of seed cotton from the Mexican variety in a day.

During recent years, cotton breeders have developed a number of rather small-boll, early, and high-yielding varieties which have replaced many of the easy-picking, large-boll kinds grown before the advent of the cotton boll weevil (*Anthonomus grandis*). This study was made to measure the picking qualities of 16 widely grown cotton varieties and to find the relationships between the time required to pick and the cost of picking the cotton and the length of lint, lint percentage, size of boll, and other fruiting characters of the varieties. The application of the results of this study to the yields and money values of the cotton varieties in this experiment will be presented in a later paper.

Workers (5) at the Cotton Branch Experiment Station at Marianna, Arkansas, calculated the number of days required to pick 500 pounds of lint from a large number of varieties under test there. The results are based on the amount of lint the average boll of each variety produced. The boll-lint-yield method used does not take into consideration other important factors. The conclusion was made that with only a small amount of experimental error, distinctions between small-boll varieties, medium-boll varieties, and large-boll varieties seem thoroughly reliable. The calculated number of days required to pick 500 pounds of lint for one test and year varied from 5.05 days for Mebane, a large-boll variety, to 9.26 days for Delfos 911, a small-boll variety.

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[2] Assistant Agronomist.

[3] Reference by number is to "Literature Cited," p. 43.

MATERIALS AND METHODS

All of the varieties used in this study were tested for yield in the regular cotton varietal experiment at the Georgia Experiment Station during the 3-year period 1930–32. The fruiting characters given were determined from averages of 50-boll samples of seed cotton picked at the second or middle harvesting date. A 50-boll sample was picked from each of the seven series of plats of each variety in 1930 and from each of the six series planted in 1931 and 1932. The length of lint was measured by cotton classers of the U. S. Dept. of Agriculture.

The time of picking each variety was obtained by recording in the field the time required by each picker to harvest all of the cotton open on each plat at the first and second pickings in 1930 and 1932 and the first, second, and third pickings in 1931. The plat size was 1/55 acre in 1930, 1/48 acre in 1931, and 1/40 acre in 1932, and the average annual acre yields for all varieties were 1,686, 1,443, and 944 pounds of seed cotton, respectively. The plats were arranged in randomized blocks (1). From 15 to 20 adult pickers were used and the varieties were harvested as planted in the field so that no one person was likely to do a large part of the harvesting of any single variety. There was considerable variation in the rate of picking of the persons and also between picking dates. From 12 to 18 records were taken on each variety each year, but it was necessary to discard a few each year because of obvious variations due to slow harvesting and other undetermined causes. The minutes required to pick the cotton of each varietal plat were divided by the number of pounds of seed cotton harvested and the quotient multiplied by 100 to get the number of minutes required to pick 100 pounds of seed cotton. The data for each variety were averaged and the probable errors of the means determined for each of the 3 years. The low probable errors show that many of the differences between varieties are significant. Three-year averages of all the data for each of the 16 varieties tested each year are given in Table 1. The correlation coefficients presented in Table 2 were prepared from the data in this table.

LENGTH OF LINT

As a group, the short staple varieties have the shortest picking time and also the lowest cost of harvesting the lint, as shown by the significant correlation coefficient of .492 between time and staple

TABLE 1.—*Fruiting characters and time and cost of picking cotton varieties at Experiment, Georgia, for the 3-year period, 1930–32.*

Variety	Length of lint in 32nds inch	Lint percentage	No. lbs. seed cotton required for 500 lbs. lint	No. bolls required for 1 lb. seed cotton	No. bolls required for 500 lbs. lint	No. minutes required to pick 100 lbs. seed cotton	No. bolls picked per hour	No. hours required to pick 500 lbs. lint	Cost of picking 500 lbs. lint at 60c per 100 lbs. seed cotton	Cost of picking 500 lbs. lint at 10c per hour
Arkansas Rowden 40......	31	36.5	1,374	56	76,461	235±6	1,422	54.0	$8.24	$5.40
Rucker 1................	27	44.4	1,127	67	75.553	250±7	1,620	47.1	6.76	4.71
College 1................	31	35.9	1,401	63	87,625	265±8	1,425	61.5	8.41	6.15
Piedmont Cleveland......	28	36.6	1,369	66	90,393	271±7	1,465	61.8	8.21	6.18
Wilson Type............	29	37.0	1,352	71	96,530	274±10	1,587	62.0	8.11	6.20
Half and Half............	26	46.4	1,079	62	67,365	275±8	1,367	49.5	6.48	4.95
Delta and Pine Land 4–8..	32	40.8	1,228	69	85,169	291±10	1,447	59.8	7.37	5.98
Lightning Express........	34	36.5	1,373	76	104,388	296±7	1,545	67.6	8.24	6.76
Half and Half (new strain).	29	43.1	1,162	66	76,395	297±8	1,344	57.8	6.97	5.78
Deltatype..............	37	34.9	1,439	66	95,810	301±8	1,327	72.5	8.63	7.25
Stoneville 2.............	33	38.1	1,314	69	91,027	306±10	1,360	67.1	7.88	6.71
Coker Cleveland 884......	32	36.9	1,355	66	89,894	314±10	1,268	71.0	8.13	7.10
Burdette Trice...........	31	35.9	1,394	71	99,476	317±9	1,367	73.9	8.37	7.39
Delfos 6102.............	35	37.0	1,351	76	102,203	318±9	1,443	71.7	8.11	7.17
Delta and Pine Land 10....	32	39.3	1,273	73	92,948	323±8	1,360	68.7	7.64	6.87
Burdette Acala...........	31	37.0	1,351	68	91,914	333±11	1,265	75.6	8.11	7.56

length and the highly significant coefficient of .717 between the picking cost and the staple length of the varieties. The tendency for the very short staple varieties to have short periods for picking is no doubt due in part to the fact that most of these varieties have large bolls. The high positive relationship between picking cost and short lint is due largely to the fact that most of the short lint varieties have both large bolls and high lint percentages, or comparatively few pounds of seed cotton per bale of lint. The seed cotton of short lint varieties does not adhere to the burs as much as long lint varieties. A few of the very short staple cottons have a tendency to fall out of the burs onto the ground, especially during stormy weather. Seed cotton of the Half and Half and Piedmont Cleveland varieties fell from the burs in rather large quantities during 1932. Under some conditions the lack of ability to stick in the bur would increase the cost of picking.

TABLE 2.—*Simple correlation coefficients between the time required to pick 100 pounds of seed cotton, the cost of picking 500 pounds of lint cotton at 10 cents per hour, and other characters of cotton varieties.**

Characters	Correlation coefficients	
	Time to pick seed cotton	Cost of picking lint cotton
Length of lint in 32nds inch	.492	.717
Lint percentage	—.210	—.728
No. bolls required for 1 pound seed cotton	.638	.538
No. bolls required for 500 pounds lint	.567	.830
No. bolls picked per hour	—.593	—.496
No. hours required to pick 500 pounds lint	.834	—
Cost of picking 500 pounds of lint at 60 cents per 100 pounds of seed cotton	.207	.710
Cost of picking 500 pounds of lint at 10 cents per hour	.834	—
No. minutes required to pick 100 pounds of seed cotton	—	.834

*According to table presented by Snedecor and Wallace (4) where N = 16, the least significant value for r is .497 while the least highly significant value for r is .623.

LINT PERCENTAGE

The negative correlation coefficient of — .210 for time or rate of picking and lint percentage is not statistically significant. That the high lint percentage varieties are somewhat easier to pick than varieties with low lint percentages may be accounted for in part by the tendency of these varieties to have rather large bolls and short lint.

The significant coefficient of — .728 for cost of picking and lint percentage shows that lint from the high linting varieties, as a group, can be harvested at a much lower cost than lint from the low percentage cottons. This is no doubt due largely to the fact that much less seed cotton is required for a bale from the high percentage varieties than from the low percentage ones. The pounds of seed cotton required for 500 pounds of lint vary from 1,079 pounds for Half and Half, a very high lint percentage variety, to 1,439 pounds for Deltatype, a variety with a low ratio by weight of lint to seed. Under some conditions, the value of the seed from low lint percentage varieties would pay for the increased cost of picking these varieties.

BOLL SIZE

The boll size of the varieties is the most important character which determines the amount of seed cotton a picker can harvest in a given time. The large correlation coefficient of .638 for the picking time and the boll size for the 16 varieties indicates that the large boll ones can be hand-picked much more rapidly than the small boll varieties. This would be expected when yields of large and small boll varieties are about the same as in these experiments, since fewer bolls are needed for a given poundage of the large-boll varieties than must be picked from the small-boll varieties.

The number of bolls per pound of seed cotton is closely related to the cost of picking the lint, as shown by the coefficient of .538 for these two variables. The reason why this relationship is not as close as the one for time and boll size is probably because the lint percentage is also a very important factor in the cost of harvesting the lint from different varieties, as has already been shown. For example, Arkansas Rowden 40 has the largest bolls and the shortest picking time of all the varieties, but its lint percentage is below the average and its picking cost higher than that of most of the high lint percentage varieties.

BOLLS PER BALE

The number of bolls per bale depends on the boll size and the lint percentage. The correlation coefficient of .567 between picking time and bolls per bale indicates that pickers can gather a bale of lint from large-boll varieties in less time than from small-boll sorts.

The highly significant correlation coefficient of .830 between the cost of picking the lint and the number of bolls per bale establishes the fact that varieties with small numbers of bolls per bale have relatively low harvesting costs.

NUMBER OF BOLLS PICKED PER HOUR

The number of bolls picked per hour for each of the varieties was calculated from the time of picking records and the number of bolls required for one bale. The negative coefficient of — .593 for the time to pick and the number of bolls picked per hour points out the tendency of varieties which release the cotton from the bur without much effort on the part of the picker to have a short picking time. It might be thought that a picker could harvest a larger number of bolls per hour from the small-boll and prolific varieties, such as Burdette Trice and Delta Pine Land 10, than from the rather large-boll varieties, such as College 1 and Piedmont Cleveland, but the data do not support this assumption.

The group of varieties from which pickers can gather a large number of bolls per hour have a relatively low harvesting cost per bale, as shown by the negative correlation coefficient of — .496 for these two variables.

HOURS TO PICK BALE

The rate of picking the seed cotton is closely associated with the hours required to harvest a bale of lint as shown by the coefficient of .834 for these characters. Although the lint percentage has been shown to be an important variable in this relationship, it is not of sufficient importance to affect it to a large extent.

COST OF PICKING 500 POUNDS OF LINT

When seed cotton is not picked by the grower, it is picked on a rate-per-100-pound basis. The rate used in this study was 60 cents per 100 pounds of seed cotton for each of the 3 years. The correlation coefficient of .207 between the time to pick the seed cotton and the cost of picking the lint on a seed cotton basis is not significant, but the coefficient of .834 where the cost is on an hour basis is very highly significant. The seed cotton basis cost does not take into full consideration differences in the proportion of seed to lint for the varieties.

SUMMARY AND CONCLUSIONS

The group of varieties with short lint and high lint percentages has a shorter picking time and a lower harvesting cost per bale of lint than the group of varieties with long lint and low lint percentages.

The large-boll varieties with a small number of bolls per bale of lint have a very much shorter time required to pick the seed cotton and a significantly lower harvesting cost per bale of lint than the medium- and small-boll varieties with a large number of bolls per bale of lint.

The number of bolls picked per hour for the 16 varieties was negatively correlated with the number of pounds of seed cotton picked per hour and with the cost of picking the lint.

The time required to pick a bale of lint was highly and positively correlated with the time required to pick 100 pounds of seed cotton.

The cost of picking the lint was highly and positively correlated with the time required to pick the seed cotton on an hour basis but not on a seed cotton basis.

LITERATURE CITED

1. EDEN, T., and FISHER, R. A. Studies in crop variation. Jour. Agr. Sci., 19: 548–621. 1927.
2. MYERS, LAWRENCE, and COOPER, MAURICE R. Cotton statistics and related data for agricultural workers. U. S. D. A., Bur. Agr. Econ., Div. Stat. & Hist. Res. November, 1932. (Page 94.)
3. WATKINS, JAMES L. King Cotton. New York: Watkins & Sons. 1908.
4. WALLACE, H. A., and SNEDECOR, GEORGE W. Correlation and Machine Calculation. Iowa State College. Rev. Ed. 1931. (Page 63.)
5. Final report of an experiment with commercial cotton varieties in delta land. Ark. Agr. Exp. Sta. Cotton Branch Sta. Data Sheet No. 11. 1932.

STUDIES ON THE TECHNIC OF CONTROL HARDINESS TESTS WITH WINTER WHEAT[1]

ARTHUR ANDERSON and T. A. KIESSELBACH[2]

In view of the growing practice of testing crop plants for cold endurance under controlled conditions, the following studies with winter wheat at the Nebraska Agricultural Experiment Station may be of interest in connection with the technic of such investigation. These data were secured in connection with a wheat breeding project which has been reported elsewhere.[3] The control equipment described by Peltier[4] was available for the freezing of these plants. In part these tests correspond with those reported for alfalfa by Peltier and Tysdal.[5]

USE OF FIELD-HARDENED PLANTS

Field-hardened plants were used in these cold endurance tests and the experience with them suggests that controlled hardening is unnecessary in such studies. The plants involved were grown in soil-filled wooden boxes 17 x 19 x 5 inches. The seed was sown at half-inch intervals in rows 2½ inches apart and in seven rows per box. At the time of planting, October 17, 1929, the boxes were placed side by side in a shallow excavation in the wheat field with their tops level with the soil surface. They were retained in this exposure until removed, a few at a time, to the freezing chamber at various intervals throughout the winter. The soil in the boxes was kept well watered until it became frozen in November. Following a thaw in late December, the soil was again watered in order to maintain favorable moisture conditions. A field count of the plants on November 12 indicated good and comparatively uniform stands in all boxes with an average of 35 plants per row. In order to limit the growth somewhat, planting was delayed until the latter part of the normal planting season.

VARIETIES INCLUDED IN TECHNIC STUDIES

In connection with a cold endurance test of new selections, three varieties of known hardiness were included in each box to serve as controls. These three varieties were, in the order of ascending hardiness, Blackhull, Nebraska 60, and Minturki. In order to study place effect in the box, additional plantings of these varieties were made in such a manner that Blackhull and Minturki were each represented in both an interior and marginal row in each box, and in addition there were two interior rows of Nebraska 60 and one of Cheyenne. As reported by Quisenberry and Clark,[6] the cold survivals of Blackhull, Nebraska 60, and Minturki as an average for 9 years under field conditions at 9 to 21 stations in the United States and Canada were 42, 59, and 65%, respectively. Since their comparative hardiness under field conditions in general has been so thoroughly appraised by these uniform nursery tests, interest attaches to their comparative reaction to control freezing under a variety of conditions and at successive intervals during the winter.

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[2] Agronomists.

[3] KIESSELBACH, T. A., and ANDERSON, A. Breeding winter wheat for resistance to stinking smut (*Tilletia levis* and *Tilletia tritici*). Nebr. Agr. Exp. Sta. Res. Bul. 51. 1930.

[4] PELTIER, G. L. Control equipment for the study of hardiness in crop plants. Jour. Agr. Res., 43: 177–182. 1931.

[5] PELTIER, G. L., and TYSDAL, H. M. A method for determination of comparative hardiness in seedling alfalfas by controlled hardening and artificial freezing. Jour. Agr. Res., 44: 429–444. 1932.

HARDENING TEMPERATURES IN THE FIELD

Since the plants under investigation were field hardened, it is of interest to note the field temperatures from the date of planting, October 17, 1929, to the end of the experiment, February 27, 1930. The maximum, minimum, and mean air temperatures prevailing prior to removal of the plants to the control freezing chamber are shown in connection with Table 3.

The mean air temperature for November was 1°C, or 3° below normal. A minimum of — 18°C occurred on November 22. The mean temperature for December was — 2°C, or 1° above normal with a minimum of — 19° on December 18. The last week averaged 9°C above normal. The January mean, on the other hand, was — 10°, or 5° below normal. A minimum temperature of — 27° occurred on January 17 with a range in minimum temperature of — 18° to — 27°C from January 14 to January 23. During February the minimum temperature was — 17° on the 15th. The February mean was 5°, or 9°C above normal.

MANNER AND EXTENT OF CONTROLLED FREEZING

Controlled freezing tests with the three varieties were made on 11 different dates between November 26 and February 26. As reported in Table 3, soil temperatures determined by thermo-couples imbedded approximately ¾ inch deep in the individual boxes ranged in the various tests from 3° to — 16°C at the beginning of the freezing period and from — 14° to — 29° at the time the boxes were removed from the freezing chamber. The boxes were retained in the freezing chamber from 22 to 35 hours. An average air temperature of approximately — 25° was maintained in the freezing chamber, with an average minimum of — 30°C. The duration of freezing was dependent upon the time required to attain the desired minimum soil temperature which was established by an estimated hardiness of the plants at each freezing period. Except where otherwise stated, the boxes with frozen plants were placed in a greenhouse maintained at a temperature of 20°C immediately after removal from the freezing chamber.

The data reported for the individual tests in Tables 3 and 4 are averages for replicate rows frozen on any given date. Those in Tables 1 and 2 are averages obtained from rows involved in the various tests conducted during the winter. Statistical constants were calculated from differences in percentage survival between paired rows within a box.

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[6] QUISENBERRY, K. S., and CLARK, J. A. Hardiness and yield of winter wheat varieties. U. S. D. A. Cir. 141. 1930.

TESTING OF VITALITY AFTER FREEZING

Readings to determine the percentage of surviving plants were made at 10-, 20-, and 30-day periods after freezing (Table 1). It is evident that the number of plants which were apparently recovering 10 days after freezing was greater than at the end of 20 and 30 days. This is due to the injury of some plants which at first showed signs of life but later succumbed. Varietal differences in survival at all periods were statistically significant, but there was a decided tendency for the differences to become increasingly significant with delay in making final readings. The nonhardy variety decreased progressively more in the number of plants surviving than did the hardy sorts. Where precise results are desired, it is important therefore to allow ample time before making the survival readings. The period required will undoubtedly vary with conditions affecting recovery.

TABLE 1.—*Comparative survival of three winter wheat varieties 10, 20, and 30 days after exposure to low temperatures under controlled conditions, averages for 55 rows of each variety.*

Days after freezing	Actual survival, %			Relative survival, %		
	Blackhull	Nebr. 60	Minturki	Blackhull	Nebr. 60	Minturki
10	42	77	81	100	100	100
20	31	66	72	74	86	89
30	27	63	70	64	82	86

EFFECT OF ROW POSITION IN THE BOX

The results of those boxes in which two varieties were grown in both marginal and interior rows have been divided into two groups according to the relative percentage of surviving plants. This affords a study of the effect of position within the box upon survival. It would seem (Table 2) that under the conditions of these tests no great error need be expected from this source. This is of especial interest in case of rows adjacent to the sides of the box. Under severe freezing conditions, 16 and 20% of the Blackhull plants survived in the marginal and interior rows of the box, respectively, whereas 67 and 57% of the Minturki survived under corresponding conditions. Where the freezing was relatively light, 67% of the Blackhull survived in both interior and marginal rows, whereas for Minturki the survival was 90% at the margin and 92% in the interior. Variation in survival between the two interior rows of Nebraska 60 was practically as great as that between the marginal and interior rows of Blackhull and Minturki. The only difference approaching statistical significance was that of 10% in favor of the marginal rows of Minturki. Since the difference was not highly significant statistically and since no explanation can be offered, it would seem logical to attribute it to chance errors.

TABLE 2.—*Comparative survival in percentage of winter wheat with respect to position in box when exposed to low temperatures under controlled conditions.*

Tests grouped according to degree of survival	Variety and row number*						
	Black hull 1	Cheyenne 2	Minturki 3	Nebr. 60 4	Blackhull 5	Nebr. 60 6	Minturki 7
Intermediate survival, av. 13 boxes....	67	88	92	87	67	89	90
Low survival, av. 9 boxes...........	16	62	57	50	20	56	67

*Rows 1 and 7 were planted at the edges of the box and are to be compared with rows 5 and 3, respectively.

EFFECT OF DEGREE OF HARDENING

It is suggested by the data in Table 3 that wheat plants acquire increased winter hardiness in the field as the cold intensity increases. Likewise, they may decrease in cold resistance following a few warm days in winter as indicated by the tests on December 27 and February 18 and 26. As the crop loses in hardiness with the approach of early spring, its cold endurance is reduced. With the exception of two changes in ranking between Nebraska 60 and Minturki, these three standard varieties of known cold endurance ranked in the same hardiness order in the 11 comparisons. There were, however, a number of rather striking fluctuations in the relative degree of survival among the three varieties. It is possible that this reflects a differential varietal adjustment to environmental conditions. The tests on January 17 and 31 suggest a differential response with respect to Nebraska 60. Blackhull and Minturki, under what appeared to be relatively similar conditions of exposure, showed about the same survival in the two tests, whereas survival of Nebraska 60 was materially lower in the second test. The difference in favor of Nebraska 60 over Minturki on January 17 was not found to be significant whereas the difference in favor of Minturki on January 31 was statistically significant. The differences in favor of Nebraska 60 compared with Blackhull were highly significant in both of these tests, but the odds were materially lower in the second test. Probably such differences in varietal response as have here occurred at various intervals during the winter correspond with the occasional reversals of varietal hardiness in different seasons under field conditions.

EFFECT OF RAPIDITY OF SOIL TEMPERATURE CHANGES UPON SURVIVAL

Some interest attaches to the question of what relation may exist under controlled conditions between the recovery of frozen plants and the rapidity of either the freezing or thawing of the soil. The data in Table 4 indicate a higher survival where these changes are slow than where they are relatively rapid.

In a comparative freezing test on February 26 and 27, with field-hardened plants, the temperature of the soil for one set of plants was lowered to — 14°C in 11 hours time, while with a duplicate set of

TABLE 3.—*Comparative survival of three varieties of winter wheat when exposed to low temperatures under controlled conditions at various dates following natural winter hardening in the field, 1929–30.*

Date of testing for cold endurance	No. of replicates (rows) frozen	Hours in freezing chamber	Temperature, °C						Percentage survival 30 days after controlled freezing		
			In field since previous test			In freezing chamber					
						Soil		Air, minimum			
			Maximum	Minimum	Mean	Maximum	Minimum		Blackhull	Nebr. 60	Minturki
Nov. 26	2	22	27	—18	5	—3	—20	—25	26	73	83
Dec. 5	3	30	16	—14	—2	—2	—26	—31	8	68	61
Dec. 12	4	26	9	—11	—1	—1	—23	—25	21	69	79
Dec. 20	5	30	7	—19	—4	—13	—26	—30	55	86	93
Dec. 27	7	31	14	—17	—3	—1	—20	—27	39	74	88
Jan. 9	10	32	17	—18	0	—16	—25	—30	49	74	81
Jan. 17	10	35	—2	—24	—14	—12	—29	—33	12	61	60
Jan. 24	10	30	—4	—27	—17	—13	—27	—32	9	52	59
Jan. 31	10	30	2	—17	—8	—4	—29	—30	12	45	58
Feb. 18	3	27	17	—17	3	3	—23	—26	1	6	33
Feb. 26	3	28	21	0	11	1	—14	—16	13	50	64
Field Controls											
Dec. 12	2	—	—	—	—	—	—	—	99	96	97
Feb. 25	8	—	—	—	—	—	—	—	63	90	88

plants retained at a somewhat higher temperature, 28 hours were required to reach the same soil minimum. The plants in both instances were removed from the freezing chamber to the warm greenhouse as soon as the soil temperature registered — 14° as determined by the potentiometer readings. A weighted survival average in the boxes having the soil temperature slowly reduced was 51% compared with 6% for the rapid reduction.

In another test on these same days, the minimum soil temperature of — 18°C was reached in 13 hours by rapid freezing and 46 hours by slow freezing. Duplicate sets of plants were given identical treatment until removal from the freezing chamber. Immediately after freezing, one set was placed in a warm greenhouse with a constant temperature of 20°C and the other set was held in a hardening room for 6 days at a temperature slightly above freezing before removal to the warm greenhouse.

These data, which are reported in Table 4, indicate (1) that slow freezing again resulted in somewhat greater survival and (2) that slow thawing of the soil after freezing tended to increase slightly the percentage of surviving plants.

TABLE 4.—*The effect of slow and rapid changes in soil temperature, under controlled conditions, upon the survival of winter wheat.*

Date of testing for cold endurance*	Total number of rows frozen	Hours in freezing chamber	Freezing chamber temperature, °C			Days in hardening room†	Percentage survival			
			Soil		Air, minimum		Blackhull	Nebr. 60	Minturki	Av. of 12 selections (1 row ea.)
			Maximum	Minimum						
Feb. 26	21	11	1	—14	—29	0	2	9	1	7
Feb. 27	21	28	1	—14	—16	0	13	50	64	57
Feb. 26	21	13	1	—18	—31	0	0	0	0	0
Feb. 26	21	13	1	—18	—31	6	1	6	2	2
Feb. 27	21	46	1	—18	—21	0	2	9	5	9
Feb. 27	21	46	1	—18	—21	6	0	15	8	12

*See Table 3 for field temperatures previous to date of freezing.

†Temperatures maintained at slightly above freezing after removal from the freezing chamber in order to retard thawing.

It would seem that the same degree of cold may affect wheat plants differently in accordance with the rapidity of either the fall or rise of the soil temperature. It should be borne in mind that in these tests the moisture content was fairly uniform due to similar treatment of the boxes. Such uniformity is important in controlled hardiness comparisons because changes in soil temperature are known to occur far more rapidly in relatively dry than in wet soils.

CORRESPONDENCE OF CONTROLLED AND FIELD HARDINESS TESTS

That controlled hardiness tests may be substituted for field survival tests is evidenced by the data in Table 5. Here the controlled

TABLE 5.—*Comparative percentage of cold survival of three varieties of winter wheat under controlled freezing conditions and in the U. S. Dept. of Agriculture uniform winterhardiness tests.*

Variety	Kind of test		
	Controlled freezing, 1930*	U.S.D.A. winterhardiness nurseries, 9 to 23 stations per year	
		1930†	9-year average 1921–29‡
Minturki	70	68	65
Nebraska 60	63	61	59
Blackhull	27	46	42

*From Table 1. These percentages are inclusive of larger populations and differ slightly from those published in Table 11, Nebr. Agr. Exp. Sta. Res. Bul. 51.

†The unpublished 1930 U. S. Dept. of Agriculture data were supplied by K. S. Quisenberry and J. A. Clark.

‡Quisenberry, K. S., and Clark, J. A. *Op. cit.*

freezing results are compared for the same varieties as tested in the U. S. Dept. of Agriculture winterhardiness nurseries during a 9-year period, 1921–29.[7] In these nurseries the survivals of Blackhull, Nebraska 60, and Minturki for the 9 years were 42, 59, and 65%, respectively. Corresponding survivals for 1930 were 46, 61, and 68% compared with 27, 63, and 70% for the controlled tests.

[7] QUISENBERRY, K. S., and CLARK, J. A. *Op. cit.*

COLD RESISTANCE ADJUSTMENTS OF FIELD-HARDENED WINTER WHEATS AS DETERMINED BY ARTIFICIAL FREEZING[1]

C. A. SUNESON AND GEORGE L. PELTIER[2]

The measurement of the relative cold resistance of varieties and selections of cereal and forage crops by means of artificial freezing is now an established part of the several improvement programs at the Nebraska Agricultural Experiment Station. The usual procedure for testing winter wheat consists of growing and hardening seedlings in flats, under field conditions, prior to artificial freezing. In this paper the progressive actual and changing relative cold tolerance relationships of two such field-grown varieties from November to January in 1930–31 and of four from November to April in 1931–32, are reported.

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[1] The data on which this paper is based were obtained in connection with the cooperative wheat improvement program, this phase being cooperative between the Departments of Agronomy and Plant Pathology, Nebraska Agricultural Experiment Station, Lincoln, Nebr., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Journal series paper No. 132 of the Nebraska Agricultural Experiment Station. Received for publication March 4, 1933.

[2] Junior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Plant Pathologist, Nebraska Agricultural Experiment Station, Lincoln, Nebr., respectively.

EXPERIMENTAL METHODS

Flats of the size and field arrangement described by Kiesselbach and Anderson (2)[3] were used in these experiments. Each freezing lot consisted of eight flats (or replications). All of the varieties to be compared were grown in each unit, since variability between flats had been found to be greater than variability within flats. Varietal populations in each of the replicates consisted of from 20 to 25 plants.

Except for a rabbitproof fence, the flats had no special care or protection during the winter. The plants were grown on the same level, made similar growth, and produced the same number of fall tillers as adjacent nursery wheat. Spring survival in the control flats was in agreement with that in near-by nursery rows. It seems, therefore, that this method of growing winter wheat plants did not induce any pertinent abnormalities in their growth or reaction up to the time active spring growth began.

The actual freezing was done in the chamber described by Peltier (3). A constant freezing period of 24 hours with different temperatures on the several dates, depending upon the degree of hardening, was employed. The object was to produce a degree of killing permitting a maximum differentiation between varieties on each date. In this paper the freezing temperatures employed are reported in terms of the minimum air temperature maintained during the 24-hour periods. The mean air temperature for any period was approximately 3° to 4° F warmer. Soil temperatures were not recorded, but it is known (4) that unless the soil is very dry the mean air temperature is not even closely approached in a 24-hour period. After freezing the flats were removed directly to a warm greenhouse.

Survival notes were generally recorded 2 weeks after freezing. It has been shown by Peltier and Tysdal (4) that mortality continues to express itself in alfalfa after this time. This holds for winter wheat also, but for practical and economical classification it is believed that survivals can be evaluated relatively 2 weeks after freezing, or even sooner in some instances.

There was some disparity in survival at successive dates following freezing, but the relative varietal agreement was nevertheless very good. Statistical evidence of this was afforded through a comparison of the survival 11 days after freezing and in other cases from 18 to 38 days after freezing with the standard 14-day record. The χ^2 test for goodness of fit applied to these four populations gave P values of from 0.20 to 0.38. The correlation coefficient based on the same contrasted comparisons gave a value of 0.808 ± 0.059.

WEATHER REVIEW

The early winter of 1930–31 was characterized by slowly receding maximum temperatures and nearly constant minimum temperatures during progressive 2-week periods. Temperature and precipitation data for the periods considered are presented in Table 1.

The early winter of 1931–32 was unusually mild. Beginning in late December an unusual condition for this section persisted for a 6-

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[3] Reference by number is to "Literature Cited," p. 58.

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week period during which the soil was free of frost but covered with snow. At the end of the period considerable desiccation of the older leaves was observed and some new growth was in evidence. A sharp drop in temperatures on March 5 following a period of warm weather caused considerable killing of unprotected wheat. A snow cover of 3 inches prevented killing in the field-control flats. Limited heaving injury occurred early in December, but this apparently affected all varieties in about the same degree, as is shown by the similarity of varietal survivals in the control flats.

TABLE 1.—*Field temperatures and precipitation for 2-week periods during the seasons of 1930–31 and 1931–32.*

Periods	1930–31				1931–32			
	Air temperature, °F			Precipitation, inches	Air temperature, °F			Precipitation, inches
	Maximum	Minimum	Mean		Maximum	Minimum	Mean	
Oct. 20–Nov. 2	75	17	34	T*	82	28	54	0.15
Nov. 3–Nov. 16	71	20	51	0.59	80	25	52	1.61
Nov. 17–Nov. 30	68	15	37	2.68	62	20	35	4.00
Dec. 1–Dec. 14	64	17	35	0.06	49	18	33	0.84
Dec. 15–Dec. 28	49	14	30	0.10	55	23	41	0.05
Dec. 29–Jan. 11	51	14	33	T	46	—3	24	1.19
Jan. 12–Jan. 25	—	—	—	—	42	0	24	1.11
Jan. 26–Feb. 8	—	—	—	—	45	—9	17	0.39
Feb. 9–Feb. 22	—	—	—	—	45	11	28	0.90
Feb. 23–Mar. 7	—	—	—	—	68	0	36	0.55
Mar. 8–Mar. 21	—	—	—	—	56	0	27	0.41
Mar. 22–Apr. 4	—	—	—	—	65	24	49	0.10

*T = Trace.

EXPERIMENTAL RESULTS

In certain experiments conducted during the winter of 1930–31, in which Blackhull and Minturki served as checks, it was noted that there was a marked accentuation in the survival spread between these varieties from early November to late December. Data from these experiments are presented in Table 2. Similar trends had previously been observed by the senior author in Kansas (7). The abnormalities reported by Hill and Salmon (1) may have been manifestations of the same phenomena.

Fairly low temperatures occurred early in the fall of 1930, as shown in Table 1, the minimum recorded in any 2-week period between October 20 and January 11 ranging from 14° to 20° F. Despite the unusually slight changes in minimum and mean temperatures during the period, there was a marked increase in the difference between the two varieties and an equally notable change in the ability of the plants to endure cold. Thus, on November 18, a minimum air temperature of 0° F maintained in the freezing chamber during the 24-hour period produced greater mortality than did a temperature of — 20° F on January 3. This increase in hardiness and the change in relative varietal relationships must be regarded, therefore, as resulting from the differential varietal response to fluctuating and moderately cold temperatures combined with attendant seasonal influences rather than to mere exposure to specific low temperatures.

TABLE 2.—*Comparative survivals of the control varieties in the freezing experiments during 1930–31.*

Number of flats frozen	Date frozen	Miminum air temperature during freezing period, °F	Survival, %	
			Blackhull C. I. No. 6251*	Minturki C. I. No. 6155*
6	Nov. 12	3	72	88
6	Nov. 18	0	5	26
16	Nov. 28–29	—6	52	79
9	Dec. 5	—6	38	88
15	Dec. 6–7	—8	27	72
23	Dec. 19–21	—17	10	50
8	Jan. 3	—20	9	53

*Accession number of the Division of Cereal Crops and Diseases.

Freezing tests in 1931–32 began on November 2 following the first killing frost of the season. Four varieties of winter wheat of known hardiness, *viz.*, Blackhull, Kawvale, Nebraska No. 60, and Minturki, were seeded in rows in quarter sections of the flats. All flats were seeded October 10 and emerged on October 19. Lots were frozen at successive 2-week intervals until late March. Data on comparative survivals are included, with other pertinent data, in Table 3.

Of particular significance at the early dates is the fact that differences in the relative survival of the varieties were slight and that only moderate hardening had taken place. On successive freezing dates the temperatures employed were lowered to compensate for additional hardening which seems to have reached a maximum about January 1. From this time until spring growth began there was a progressive reduction in hardiness as indicated by the higher temperatures employed.

The results, however, show more than the seasonal rise and fall of cold tolerance. Considering Nebraska No. 60 as a standard and expressing the survival of the other varieties as a percentage of this standard on successive dates, as shown in Table 3, it is apparent that considerable variation in the relative cold-resistance relations of varieties attends seasonal and environmental variations under field conditions. Thus, the lot frozen November 2 discloses the varietal ranking, in order of increasing cold endurance, as Kawvale, Blackhull, Minturki, and Nebraska No. 60. In this arrangement both Kawvale

TABLE 3.—*Comparative survivals of field-hardened plants of four varieties of winter wheat frozen artificially at 2-week intervals during the winter of 1931–32.*

Date frozen	Minimum freezing temperature, °F	Condition before freezing	Survival recorded	Average survival, %*				Survival in relation to Nebraska No. 60, %			
				Blackhull	Kawvale	Nebr. No. 60	Minturki	Blackhull	Kawvale	Nebr. No. 60	Minturki
November 2	9	Soil fairly dry	Nov. 10	12	8	22	16	55	36	100	73
November 16	7	Soil very wet	Nov. 25	9	20	47	40	19	43	100	85
November 30	3	Snow thawed off before freezing	Jan. 7	41	71	89	90	46	80	100	101
December 14	—3	Wet soil; slight snow cover	Dec. 29	14	62	77	86	18	81	100	112
December 28	—4	Wet soil; crust frozen	Jan. 12	23	81	92	87	25	88	100	95
January 11	—4†	Wet soil; 10 in. snow; removed	Feb. 3	65	95	97	97	67	98	100	100
January 25	—4	Wet soil; 10 in. snow; removed	Feb. 8	2	27	47	34	4	57	100	72
February 8	0	Wet soil; 10 in. snow; removed	Feb. 23	3	53	50	58	6	106	100	116
February 22	5	Wet soil; iced soil surface	Mar. 7	3	49	49	58	6	100	100	118
March 7	7	Frozen crust; 3 in. snow; removed	Mar. 22	23	63	75	81	31	84	100	108
March 21	10	Frozen crust; some snow	Apr. 5	48	73	75	79	64	97	100	105
———	—	Field controls	Apr. 5	87	87	93	89	—	—	—	—

*Based on a study of eight replications.

†Machine off part time.

and Minturki are out of line with the field hardiness reported for them by Quisenberry and Clark (5). Advancing another month, they are found in their generally recognized order, *viz.*, Blackhull, Kawvale, Nebraska No. 60, and Minturki, but with greater differences than generally occur in the field. This accentuation of varietal differences occurs frequently in controlled freezing experiments. Following this there was a period in which Minturki was depressed, probably a reaction to mild weather and prolonged snow cover without the soil being frozen. With the penetration of this snow cover by frost in early February, Minturki again asserted superiority over Nebraska No. 60, while Blackhull gave exceedingly low survivals. During February, Kawvale showed hardiness equal to that of Nebraska No. 60. March tests found all varieties in their commonly accorded ranking with a pronounced narrowing in the spread between them.

A statistical measure of the significance of these changing relative relationships is provided in Table 4 in which is used the point binomial method suggested by Salmon (6). This analysis bears out the changing relationships reflected by the averages, particularly if two or three successive lots are combined into one population.

Frequent observations during the progress of these tests showed that plants that survived a severe freezing consistently formed a new set of roots from the base of the crown. Many plants that maintained signs of life for about a week after freezing attempted but failed to establish such a root system. Plant development after severe freezing was very closely related to the rate of development of new roots, and no expansion or activity of the old roots was observed. Secondary roots were fairly well developed in these plants before freezing. It has already been pointed out that soil temperatures were never so low as air temperatures during the freezing period. It appears, therefore, that wheat roots are less hardy under certain exposures than are the crown or even the leaves and that ability to regenerate a new root system is at least sometimes a factor in survival.

The protecting effect of snow cover was well shown in these experiments. Field-control flats protected by 3 inches of snow during the March storm showed survivals greater than for any lot frozen artificially with the possible exception of the one reported for January 11, when a machine breakdown occurred. Injury to Blackhull in this lot emphasizes its particular susceptibility at that period. The slight injury to the other varieties on that date and to the entire control group as shown in April was largely induced by heaving injury early in the winter. No field killing occurred where the early March snow cover was 3 inches or more in depth.

FIELD RESULTS

Field winterkilling in eastern Nebraska has been rare in late years, but it did occur in significant proportions in 1932 in space-planted material void of snow cover during the March storm. Data from these plantings, together with the survival of the same varieties in the uniform winterhardiness nurseries, as reported by Quisenberry and

TABLE 4.—*Intervarietal pairings showing number of replicates for each variety with superior winter survival on successive dates during the winter of 1931–32 (ties omitted).*

Variety	Date frozen											Field controls
	Nov. 2	Nov. 16	Nov. 30	Dec. 14	Dec. 28	Jan. 11	Jan. 25	Feb. 8	Feb. 22	Mar. 7	Mar. 21	
Minturki	5	8	8	8	8	8	8	8	8	8	7	5
Blackhull	3	0	0	0	0	0	0	0	0	0	1	2
Minturki	6	8	8	8	5	3	5	5	6	7	6	5
Kawvale	2	0	0	0	3	2	3	3	2	1	2	3
Minturki	3	3	5	7	3	3	2	6	6	6	4	3
Nebr. No. 60	5	5	2	1	5	3	6	2	2	2	3	5
Nebr. No. 60	7	8	8	8	8	8	8	8	8	8	7	5
Blackhull	1	0	0	0	0	0	0	0	0	0	1	3
Nebr. No. 60	8	8	8	7	7	3	7	4	4	6	5	5
Kawvale	0	0	0	1	1	2	1	4	4	2	3	3
Kawvale	2	6	8	8	8	8	8	8	8	8	7	4
Blackhull	5	1	0	0	0	0	0	0	0	0	1	3

Distributions giving significant differences (point binomial method): Single freezing date, 7:1, or greater; two consecutive freezing dates, 12:4, or greater.

Clark (5), are presented in Table 5. They show that distorted relative rankings present themselves in field studies as well as in controlled experiments under certain conditions. The field data from Lincoln, Nebr., are based on plant counts of 16-foot rows replicated four times.

TABLE 5.—*Field survival of certain winter wheat varieties at Lincoln, Nebr., in 1932 compared with their average survival in the uniform winterhardiness nurseries, 1929.*

Variety	C. I. No.	Average spring survival of spaced plants in field in 1932, %	Average spring survival at 21 experiment stations in 1929, %
Minturki	6155	63.4	64.1
Nebr. No. 60	6250	55.0	58.0
Kawvale	8180	55.1	53.8
Blackhull	6251	24.6	46.2
Kanred	5146	34.3	60.7

The varieties previously reported show relative rankings much like those reported from artificial freezing in late February and early March, when the field injury actually occurred. Kanred, data on which are also included in Table 5, survived only slightly better than Blackhull and decidedly less than Nebraska No. 60. Other closely related varieties not included in Table 5 behaved in a similar manner. These field results, fortified as they are in this instance by controlled work, emphasize the need of reporting and interpreting field results in the light of the specific environment at the time injury occurred.

DISCUSSION

At first thought the results presented may seem to discredit the method of growing plants for cold-resistance comparisons under a changing field environment. This probably is not the case, however. While the environmental conditions prevailing during the period of these experiments may not conform in all respects to a so-called "normal" year, the fact remains that relative varietal relations are progressively and variably adjusted to changes in the natural environment. Knowledge of these adjustments is of importance in adequately evaluating unknown varieties for cold resistance and affords a more satisfactory basis for determining local adaptability than do comparisons based on a standardized environment.

The hardening phenomenon appears to involve more than mere exposure to low temperatures, especially when relative values are concerned. Thus, despite the fact that conditions in 1930–31 were quite unlike those in 1931–32, remarkable agreement is found in the relative survivals at any given date. This was shown by the remarkably close relative agreement noted in midwinter tests, when in one year the actual margin of cold tolerance was — 20° and in the other only — 4° F. On the other hand, field-hardened plants frozen November 2 and November 16 at 9° and 7° F, respectively (Table 3), yielded abnormal relative varietal survivals, although the same varieties hardened under controlled conditions and frozen at 11° F gave a normal differential rating. Therefore, factors other than temperature must play a rôle in the hardening process under field conditions.

The similarity of varietal survivals in controlled freezing experiments and in the field bears out the accuracy of the methods used. That the lethal temperatures established by the two methods are in agreement is of further interest. Thus, on March 6, 7, and 8, the mean field temperatures were 6°, 7°, and 4° F, respectively, whereas the minimum temperature in the controlled freezing experiments was approximately 7° F. The length of exposure and the soil mass were different but apparently compensated each other. The determination of lethal temperatures by control methods at progressive periods for field application may have a place in specialized crop reporting.

SUMMARY

Controlled freezing experiments at progressive 2-week intervals from early November to late March with field-grown plants are reported.

An increase in hardening, as expressed in the ability of wheats to endure lower temperatures, was shown from November to January, followed by a nearly equal recession in hardiness from January to late March.

Marked and statistically significant changes in the relative hardiness rank of the varieties used, Blackhull, Kawvale, Nebraska No. 60, and Minturki, were noted during the winter. These changes are attributed to hardening adjustments. Exposure to severe temperatures was essential for maximum expressions of cold tolerance, but exposures to specific hardening temperatures did not always result in the same hardiness relationships, which suggests an important rôle for other environmental and seasonal factors in the hardening phenomenon.

The demonstration of changing relative varietal relationships under a field environment may permit an explanation of the fairly frequent abnormalities associated with localized field trials and may account for some of the inconsistencies experienced in laboratory evaluations with field plants. More precise information is needed concerning the factors influencing the hardening process, but investigators can not be cautioned too strongly against a general application of results based on any one particular period or on any one specific field condition.

LITERATURE CITED

1. HILL, D. D., and SALMON, S. C. The resistance of certain varieties of winter wheat to artificially produced low temperatures. Jour. Agr. Res., 35: 933–937. 1927.
2. KIESSELBACH, T. A., and ANDERSON, A. Breeding winter wheat for resistance to stinking smut. Nebr. Agr. Exp. Sta. Res. Bul. 51, 1–22. 1930.
3. PELTIER, G. L. Control equipment for the study of hardiness in crop plants. Jour. Agr. Res., 43: 177–182. 1931.
4. ———— and TYSDAL, H. M. A method for the determination of comparative hardiness in seedling alfalfas by controlled hardening and artificial freezing. Jour. Agr. Res., 44: 429–444. 1932.
5. QUISENBERRY, K. S., and CLARK, J. A. Hardiness and yield of winter wheat varieties. U. S. D. A. Circ. 141, 1–30. 1930.
6. SALMON, S. C. The point binomial formula for evaluating agronomic experiments. Jour. Amer. Soc. Agron., 22: 77–81. 1930.
7. SUNESON, C. A. The effect of hardening on relative cold resistance of winter wheat varieties. Unpublished thesis, Kan. State Col. Agr. 1930.

THE EFFECT OF GROWING CORN AND SOYBEANS IN COMBINATION ON THE PERCENTAGE OF DRY MATTER IN THE TWO CROPS[1]

R. G. WIGGANS[2]

During the past 9 years a series of experiments have been conducted at the Cornell University Agricultural Experiment Station for the purpose of studying the possibilities of the soybean as a silage crop in combination with corn. The results of these tests are being published as Station Bulletin 548, 1932.

The plan of the experiments required plantings which included two varieties of corn and two varieties of soybeans. The varieties of corn were Luce's Favorite, a heavy-producing medium-late corn generally suitable for silage production at the lower elevations in New York State (now very largely replaced by Westbranch Sweepstakes), and Cornell 11, a medium-early corn generally suitable for grain at the lower elevations and for silage at higher elevations. The two varieties of soybeans were Wilson, an indeterminate small-seeded variety, and Medium Early Green, a determinate large-seeded variety, now largely displaced by non-shattering equally productive smaller-seeded varieties.

These two varieties of corn and the two varieties of soybeans were grown separately in three-row blocks and in combination in three-row blocks, and in addition the soybeans were grown in single rows and in three-row blocks between three-row blocks of corn (Fig. 1). This arrangement gave an opportunity to compare under very similar conditions several combinations of the two crops on a minimum of land.

In connection with these experiments it was necessary to take many shrinkage samples, since the value of silage is very largely dependent on total dry weight. The purpose of this paper is to report the effect of growing corn and soybeans in combination on the percentage of dry matter in the two crops.

In the corn and soybean work, shrinkage samples of about 40 pounds green weight were taken and weighed immediately after cutting before loss of moisture took place. These samples were then dried to constant weight at 180° F in a large drying kiln. This practice does not eliminate all moisture, but for the purposes for which the samples were used it is essentially moisture free, since all samples are dried to an extremely low uniform moisture content. The general practice in this kind of work is to calculate the average percentage dry matter of the several shrinkage samples taken from the different series of the same thing. The percentages of dry matter used in this paper, however, are individual determinations and include only those which can be paired, one sample taken from a plat where the crop was grown alone, the other where it was grown in combination.

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[2] Assistant Professor of Plant Breeding.

In all cases the pairs of dry-matter percentages were secured from adjacent plats or from plats with only one other intervening. By such an arrangement it is possible to apply Student's method in the study of the results.

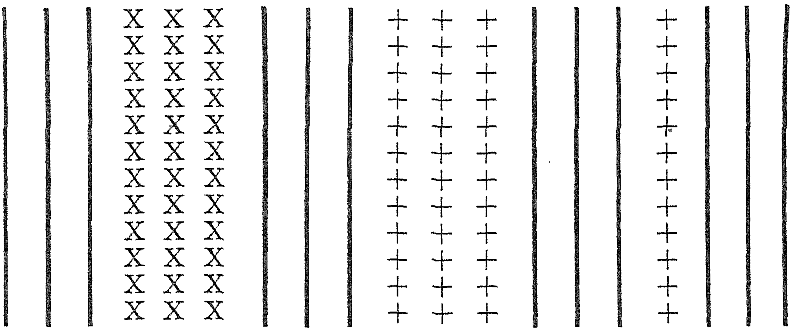

FIG. 1.—Plan of planting of one series of one variety of corn and one variety of soybeans.

▬▬ corn, XXX corn and soybeans, + + + soybeans.

RESULTS OF THE EXPERIMENTS

The percentages of total dry matter and of dry shelled grain with and without soybeans for the two varieties of corn are shown in Table 1. These data cover the 6-year period from 1923 to 1928. The percentage dry weights given in Table 1 were compared by

TABLE 1.—*Percentage total dry weights and dry weights of shelled grain in corn when grown alone and in combination with soybeans.*

Year	Luce's Favorite corn grown				Cornell No. 11 corn grown			
	Alone		With soybeans		Alone		With soybeans	
	Total	Grain	Total	Grain	Total	Grain	Total	Grain
1923	21.5	12.2	17.7	9.3	20.6	27.5	19.8	8.6
	17.5	4.3	18.7	10.3				
	19.7	13.4	18.8	9.2				
1924	15.2	5.5	15.9	4.4	17.4	11.1	18.7	6.8
	14.9	6.3	15.5	2.7	18.0	16.2	18.5	9.6
	15.1	6.5	16.8	5.2	18.7	13.2	18.3	8.1
	15.3	5.6	16.8	1.9				
1925	21.4	22.3	21.1	16.3	26.2	41.4	24.7	34.4
	20.4	23.9	19.8	23.6	25.7	40.0	22.4	29.2
1926	16.9	15.6	16.7	14.6	19.6	28.8	17.9	5.1
	16.4	9.3	15.7	7.4	19.0	25.7	18.8	28.3
					18.0	18.9	18.6	31.1
					18.7	18.7	19.2	25.5
1927	14.9	7.2	16.7	7.8	17.4	16.3	18.5	4.6
	16.1	9.9	14.7	5.2	18.7	22.9	19.2	22.4
	15.8	4.9	16.8	6.3	18.7	18.9	18.0	7.6
	17.2	10.5	17.0	4.0	18.7	18.8	18.5	13.3
1928	22.6	29.2	21.9	22.3	25.8	23.8	25.8	1.95
					25.4	23.1	25.3	28.9

Student's method in the following combinations: Column 2 with column 4; 3 with 5; 6 with 8; and 7 with 9. The results of these comparisons are given in Table 2.

TABLE 2.—*Comparison of percentages of total dry weight and dry weight of shelled grain in corn when grown alone and in combination with soybeans, 1923–28.*

Varieties of corn	Number of comparisons	Average difference between corn grown alone and in combination		Odds that differences are significant	
		Total	Grain	Total	Grain
Luce's Favorite......	16	0.02	2.26	<1:1	124:1
Cornell No. 11.......	16	0.27	5.14	4:1	45:1
Luce's Favorite and Cornell No. 11.....	32	0.15	3.70	3:1	259:1

The difference in percentage of total dry matter between corn grown alone and in combination with soybeans, although on the average positive, is insignificant. This is apparent in column 3 of Table 2 and verified by the very low odds shown in column 5. On the other hand, the differences in the percentages of dry shelled grain are undoubtedly significant, the corn grown alone giving a greater percentage of dry shelled grain than corn grown with soybeans. Cornell 11, the earlier, heavier-grain-producing variety, shows a little more than twice the difference shown by Luce's Favorite, while if the two varieties are grouped together the average difference is 3.70%. The odds presented in the last column give conclusive evidence that the differences existing between the percentage of dry shelled grain in the corn grown alone and in a combination with soybeans are significant.

A similar comparison of the effect of corn on soybeans is of interest. If there is an effect of corn on soybeans or of soybeans on corn, the former would be expected to be much greater than the latter because approximately 75% of the total growth of the combined crops is corn and 25% is soybeans. Also, by growing the crops together, corn is reduced by only about 15%, while soybeans produce not more than one-third as much as when grown alone.

The percentages of dry matter in both Wilson and Medium Early Green soybeans are given in Table 3, which is arranged to facilitate easy comparisons between soybeans grown alone and in combination with corn. The shrinkage samples used in determining the percentage of dry matter in soybeans grown in three-row blocks were taken from the central row. In the table these are presented separately from the dry matter percentages of soybeans grown in single rows with corn grown adjacent on either side. These two series cannot be compared directly because the plats were not grown sufficiently close together, but they may be compared indirectly through comparison with the dry-matter percentage of soybeans grown in combination with corn.

Various comparisons by Student's method between soybeans grown alone and in combination with corn are derived from Table 3

TABLE 3.—*Percentage total dry weights of soybeans grown alone and in combination with corn.*

Year	Varieties of corn	Wilson soybeans grown			Medium Early Green soybeans grown		
		Alone in three-row blocks	Alone in single-row blocks	In combination with corn	Alone in three-row blocks	Alone in single-row blocks	In combination with corn
1923	Luce's Favorite	25.9		28.5	28.1		29.9
		26.2		24.7			
		27.5		26.8			
			25.9	28.5		27.8	29.9
1924	Luce's Favorite	21.3		20.3	22.5		24.1
		21.5		20.0	27.1		23.5
		19.3		18.8	24.7		21.6
			22.4	20.3		22.6	24.1
			21.5	20.0		24.0	23.9
						24.1	22.5
	Cornell No. 11	19.2		19.7			
		20.6		19.6			
			18.7	19.7			
			21.7	19.6			
1925	Luce's Favorite	22.9		23.7	23.4		21.7
		22.1		23.0	23.1		22.7
			23.2	23.7		23.1	21.7
	Cornell No. 11	20.8		22.5	25.6		24.1
		21.3		24.0			
			22.7	22.5		25.6	24.1
1926	Luce's Favorite	19.4		22.8	23.0		21.9
		19.8		20.9	22.4		21.2
			19.9	22.8		21.5	21.9
	Cornell No. 11	19.6		19.7	19.5		22.1
		17.8		20.9	20.5		22.5
			18.8	19.7		20.4	22.1
1927	Luce's Favorite	29.7		32.4	31.1		34.8
		29.8		34.1	34.5		36.0
			31.9	32.7		31.9	34.8
	Cornell No. 11	34.9		32.7	33.6		35.8
		31.1		30.6	34.0		34.5
			33.1	32.7		32.8	35.8
1928	Luce's Favorite	24.0		25.7			
		25.5		28.6			
			25.7	25.7			
	Cornell No. 11	24.8		28.1	25.5		26.9
		25.6		28.2	24.0		27.4
			26.8	28.1		26.3	26.9

and presented in Table 4. Probably the most striking point to be observed in this table is the fact that the mean differences are negative with one exception. This is in the case of Medium Early Green soybeans in three-row blocks as contrasted to the same beans grown with Luce's Favorite corn. In other words, the dry-matter percentage of soybeans when grown alone is less than when grown in combination with corn. Although the differences are negative, in many comparisons they are insignificant. In column 4 of the table, the odds show that rather large differences are necessary before reasonable certainty of significance is attained. The fact that all are negative with the one exception, which is highly insignificant as shown by odds of 2 : 1, gives weight to the conclusion that in general a difference exists.

If the comparisons between the percentages of dry matter in soybeans as determined from single rows and from soybeans grown with corn are studied in a similar way, it will be noted that there is not a single significant difference, the highest odds, 11 : 1, being obtained with a combination of all varieties. Although not statistically significant, attention is called to the fact that the mean differences are all negative but in most cases less than the corresponding differences in column 3. As stated above, this is the only means of comparing the percentages of dry matter in the soybeans grown in three-row blocks and those grown in single rows between rows of corn. However, it seems fairly conclusive that the soybeans grown in single rows between rows of corn are much nearer like the soybeans grown in the same row with corn than the soybeans grown in three-row blocks.

TABLE 4.—*Comparison of percentages of total dry weight of soybeans grown alone and in combination with corn, 1923–28.*

Varieties of corn	Three-row blocks			One-row blocks			Three- and one-row blocks combined		
	Number	Mean difference	Odds	Number	Mean difference	Odds	Number	Mean difference	Odds
Wilson Soybeans									
Luce's Favorite........	14	—1.10	37:1	7	—0.46	3:1	21	—0.89	44:1
Cornell No. 11	10	—1.03	15:1	6	—0.08	<1:1	16	—0.67	13:1
Luce's Favorite and Cornell No. 11.	24	—1.07	189:1	13	—0.28	3:1	37	—0.79	92:1
Medium Early Green Soybeans									
Luce's Favorite........	10	0.25	2:1	7	—0.54	4:1	17	—0.08	<1:1
Cornell No. 11	7	—1.51	40:1	4	—0.95	4:1	11	—1.31	77:1
Luce's Favorite and Cornell No. 11.	17	—0.48	4:1	11	—0.69	9:1	28	—0.56	13:1
Wilson and Medium Early Green Soybeans Combined									
Luce's Favorite........	24	—0.54	7:1	14	—0.50	6:1	38	—0.52	8:1
Cornell No. 11	17	—1.23	179:1	10	—0.43	4:1	27	—0.93	225:1
Luce's Favorite and Cornell No. 11.	41	—0.82	95:1	24	—0.47	11:1	65	—0.69	243:1

In the last three columns of the table the two comparisons are combined. Here again is evidence that there is a difference and that on the average the percentage dry matter in soybeans in the corn is greater than that of soybeans grown alone.

The rather low odds with relatively high differences shown in Table 4 indicate large variations between samples included in the comparisons. This matter was further studied by separating the several years. The results of these comparisons are given in Table 5.

TABLE 5.—*Comparison by years of percentages dry weight of soybeans grown alone and in combination with corn.*

Year	Number of* comparisons	Mean difference between soybeans alone and in combination with corn	Odds that differences are significant
1923	6	—1.15	11:1
1924	15	0.90	44:1
1925	11	0.01	<1:1
1926	12	—1.32	142:1
1927	12	—1.54	104:1
1928	9	—1.93	1174:1

*In this table the two varieties of soybeans were combined as were also the three- and one-row blocks in comparison with the same varieties grown with the two varieties of corn.

In these comparisons the numbers are rather small, but regardless of this fact a very significant difference is apparent in the performance from year to year. The 15 pairs of samples taken in 1924 gave a positive mean difference in percentage dry matter of 0.90% between soybeans grown alone and with corn, a difference which without much doubt is significant. The following year, 1925, failed to show any difference between the two, while in 1923 there was a large negative difference, although it is of little significance due to low odds and a very limited number of observations. The other 3 years gave significant negative differences. These variations from season to season account to a considerable extent for the large mean differences necessary to show significance in Table 4.

DISCUSSION OF RESULTS

There is no questioning the fact that shading soybeans, or green plants in general, decreases the total dry-weight production. This has been shown repeatedly. Garner and Allard,[3] working specifically on soybeans, showed the reduction in total dry matter resulting when artificial shading was practiced, but did not show the effect on the percentage dry matter. Welton and Morris[4] report the same effect and also show a decrease in the percentage dry matter, a result to be expected from artificial shading. They also present data showing that the percentage dry matter of the stems of soybeans is reduced when the soybeans are grown in combination with corn. This also would be expected if light were the only factor operating. Other factors may have as much or more influence on the composition of the plant as light. Garner and Allard showed the effect of water to be greater than the effect of a reduction in light intensity. Availability of essential plant nutrients, such as nitrogen, is also suggested as influencing the general composition.

At least the varying results secured from year to year with the same varieties of soybeans grown with the same varieties of corn as given above, together with the results secured by Welton and Morris, which are not in agreement with those here presented, indicate that other factors than light are operative on the percentage dry weight. Certainly, when the two crops are grown together, the soybean plant is placed under conditions of keenest competition, with reduction of light intensity, water, and essential food nutrients.

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[3] GARNER, W. W., and ALLARD, H. A. Effect of the relative length of day and night and other factors of the environment on growth and reproduction in plants. Jour. Agr. Res., 18: 553–606. 1920.

[4] WELTON, F. A., and MORRIS, V. H. The lodging of soybeans. Jour. Amer. Soc. Agron., 22: 897–902. 1930.

CONCLUSIONS

The percentage total dry matter in corn grown with soybeans is not significantly changed, but the percentage of dry shelled grain in the total dry matter is significantly reduced.

The percentage total dry matter in soybeans grown with corn as compared to the percentage when grown alone depended on the season, and very probably on other factors, such as available nitrogen, phosphorus, etc., and available water. During the season of 1924 the percentage dry matter was higher in soybeans grown alone than when grown with corn, while in two other years no difference was shown. A significant negative effect was apparent in 3 out of the 6 years of the experiment.

TABLES FOR CALCULATING THE STANDARD ERROR AND THE PROBABLE ERROR OF THE COEFFICIENT OF VARIABILITY[1]

Hubert M. Brown[2]

In the past the computation of either the standard error or the probable error of the coefficient of variability has been a rather tedious process when those errors had to be obtained by direct substitution in the formulae:

$$\text{S. D.}_{\text{c. v.}} = \frac{\text{C. V.}}{(2\text{N})^{\frac{1}{2}}}\left[1 + 2\left(\frac{\text{C. V.}}{100}\right)^2\right]^{\frac{1}{2}} \text{ and}$$

$$\text{P. E.}_{\text{c.v.}} = \pm .6745 \text{ S. D.}_{\text{c.v.}}$$

in which C. V. is the coefficient of variability and N is the number of individuals in the population. To simplify this process Tables 1 and 2 have been prepared.

As the probable error of the coefficient of variability has been used for many years, tables which have aided in the calculation of the probable error have appeared from time to time.

One table, that of Rietz,[3] gives the value of the probable error directly for values of C. V. from 1 to 25 by integers, and for values of N by various grades. When C. V. is greater than 25, however, other tables must be used or substitutions made in the formula.

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[1] Contribution from the Department of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 148 (n. s.). Published with the approval of the Director. Received, for publication February 14, 1933.

[2] Research Assistant in Farm Crops.

[3] Rietz, H. L. Appendix in Principles of Breeding by E. Davenport. New York: Ginn & Co. 1907. (Page 710.)

TABLE 1.—*The values of A for coefficients*

C.V.	0	1	2	3	4
0	0 .707	.707 .708	1.415 .708	2.123 .710	2.833 .711
10	7.139 .733	7.872 .735	8.607 .739	9.346 .746	10.092 .751
20	14.697 .793	15.490 .802	16.292 .810	17.102 .819	17.921 .829
30	23.043 .891	23.934 .903	24.837 .914	25.751 .925	26.676 .938
40	32.496 1.016	33.512 1.030	34.542 1.044	35.586 1.058	36.644 1.073
50	43.301 1.163	44.464 1.178	45.642 1.193	46.835 1.210	48.045 1.225
60	55.642 1.324	56.966 1.340	58.306 1.358	59.664 1.375	61.039 1.391
70	69.649 1.496	71.145 1.514	72.659 1.532	74.191 1.550	75.741 1.567
80	85.417 1.676	87.093 1.695	88.788 1.712	90.500 1.732	92.232 1.750
90	103.010 1.861	104.871 1.881	106.752 1.899	108.651 1.918	110.569 1.937
100	122.474 2.051	124.525 2.070	126.595 2.089	128.684 2.108	130.792 2.127
110	143.844 2.242	146.086 2.262	148.348 2.282	150.630 2.300	152.930 2.320

*The standard error of C.V. is $\pm A/(N)^{\frac{1}{2}}$. The first differences are given to aid in

Pearson[4] divided the formula for this probable error into two factors, *viz.*, $\frac{.6745}{(2N)^{\frac{1}{2}}}$, computed for numbers from 1 to 1,000; and the remainder of the formula, computed for values of C. V. from 1 to 50. To obtain the probable error, the proper entries from these two tables are multiplied together. For values of C. V. greater than 50, direct substitution in the formula has been necessary.

The formula for the standard error of the coefficient of variability may be separated into two factors as follows:

$$\frac{1}{(N)^{\frac{1}{2}}} \text{ and } \frac{C.\,V.}{(2)^{\frac{1}{2}}}\left[1 + 2\left(\frac{C.\,V.}{100}\right)^{2}\right]^{\frac{1}{2}}$$

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[4] PEARSON, KARL. Tables for Statisticians and Biometricians. London: Cambridge University Press, Part I, Ed. 3. 1930.

*of variability (C.V.) of 0 to 119.**

5	6	7	8	9
3.544 .714	4.258 .716	4.974 .719	5.693 .722	6.415 .724
10.843 .757	11.600 .763	12.363 .771	13.134 .778	13.912 .785
18.750 .838	19.588 .848	20.436 .859	21.295 .869	22.164 .879
27.614 .951	28.565 .963	29.528 .976	30.504 .990	31.494 1.002
37.717 1.087	38.804 1.102	39.906 1.116	41.022 1.132	42.154 1.147
49.270 1.242	50.512 1.258	51.770 1.274	53.044 1.290	54.334 1.308
62.430 1.409	63.839 1.427	65.266 1.443	66.709 1.461	68.170 1.479
77.308 1.586	78.894 1.603	80.497 1.622	82.119 1.638	83.757 1.660
93.982 1.768	95.750 1.787	97.537 1.806	99.343 1.824	101.167 1.843
112.506 1.956	114.462 1.974	116.436 1.994	118.430 2.013	120.443 2.031
132.919 2.147	135.066 2.165	137.231 2.185	139.416 2.204	141.620 2.224
155.250 2.339	157.589 2.359	159.948 2.378	162.326 2.398	164.724 2.417

interpolation.

The second factor is here called A. Then, $\text{S. D.}_{\text{c.v.}} = \pm \frac{A}{(N)^{\frac{1}{2}}}$.

Table 1 gives the values of A for the corresponding values of the coefficient of variability from 0 to 119, by integers. To facilitate interpolation, the differences between each two successive values are also given. In the computation of the values of A all decimals were carried five to seven places, but these have been cut back to three decimals for simplicity. It is thought that three decimal places in A will give sufficient accuracy for all ordinary values of N because the value of N must be greater than 10,000, if the standard error is to be less than .001 even when the coefficient of variability is only unity. No table for values of the square root of N is given here because those values can be obtained from any table of squares and square roots.

The following examples show how Table 1, giving values of A, is to be used. Let N equal 100 in both examples.

TABLE 2.—*The values of B for coeffi-*

C.V.	0	1	2	3	4
0	0 .477	.477 .477	.954 .478	1.432 .479	1.911 .480
10	4.815 .494	5.309 .496	5.805 .499	6.304 .503	6.807 .506
20	9.913 .535	10.448 .541	10.989 .546	11.535 .553	12.088 .559
30	15.543 .600	16.143 .609	16.752 .616	17.368 .625	17.993 .633
40	21.918 .686	22.604 .694	23.298 .705	24.003 .713	24.716 .724
50	29.206 .784	29.990 .795	30.785 .805	31.590 .816	32.406 .826
60	37.530 .893	38.423 .904	39.327 .916	40.243 .927	41.170 .939
70	46.978 1.009	47.987 1.021	49.008 1.033	50.041 1.045	51.086 1.058
80	57.613 1.130	58.743 1.143	59.886 1.156	61.042 1.167	62.209 1.181
90	69.479 1.256	70.735 1.268	72.003 1.281	73.284 1.294	74.578 1.306
100	82.608 1.383	83.991 1.396	85.387 1.409	86.796 1.422	88.218 1.435
110	97.021 1.513	98.534 1.525	100.059 1.539	101.598 1.552	103.150 1.565

*The probable error of C.V. is $\pm B/(N)^{\frac{1}{2}}$. The first differences are given to aid in

1. $\text{C. V.} = 23.0\%,\ A = 17.102,\ \text{S. D.}_{\text{c.v.}} = \dfrac{17.102}{(N)^{\frac{1}{2}}} = \dfrac{17.102}{10} = 1.710\%$

2. $\text{C. V.} = 9.143\%,\ A \doteq 6.415 + (.724)(.143) = 6.519,\ \text{S. D.}_{\text{c.v.}} = .652\%$

As many workers are using the probable error instead of the standard error, Table 2 was set up to give the values of B for the values of C. V. from 0 to 119 by integers. The probable error then becomes $\text{P. E.}_{\text{c.v.}} = \pm \dfrac{B}{(N)^{\frac{1}{2}}}$. To facilitate interpolation the differences between each two successive values of B are also given.

The following examples show how Table 2, giving the values of B, is to be used. Let N equal 100 in both examples.

*cients of variabilty (C.V.) of 0 to 119.**

5	6	7	8	9
2.391 .481	2.872 .483	3.355 .485	3.840 .487	4.327 .488
7.313 .511	7.824 .515	8.339 .520	8.859 .524	9.383 .530
12.647 .565	13.212 .572	13.784 .579	14.363 .586	14.949 .594
18.626 .641	19.267 .649	19.916 .659	20.575 .667	21.242 .676
25.440 .733	26.173 .743	26.916 .753	27.669 .764	28.433 .773
33.232 .838	34.070 .848	34.918 .860	35.778 .870	36.648 .882
42.109 .950	43.059 .962	44.021 .974	44.995 .985	45.980 .998
52.144 1.069	53.213 1.082	54.295 1.093	55.388 1.105	56.493 1.120
63.390 1.192	64.582 1.206	65.788 1.218	67.006 1.230	68.236 1.243
75.884 1.319	77.203 1.332	78.535 1.345	79.880 1.357	81.237 1.371
89.653 1.448	91.101 1.460	92.561 1.474	94.035 1.487	95.522 1.499
104.715 1.577	106.292 1.591	107.883 1.604	109.487 1.617	111.104 1.631

interpolation.

3. $\text{C. V.} = 23.0\%,\ \text{B} = 11.535,\ \text{P. E.}_{\text{c.v.}} = \frac{11.535}{(\text{N})^{\frac{1}{2}}} = \frac{11.535}{10} = 1.154\%$

4. $\text{C. V.} = 9.143\%,\ \text{B} = 4.327 + (.488)\,(.143) = 4.397,\ \text{P. E.}_{\text{c.v.}} = .440\%$

As shown in examples 1 and 3, when the value of the coefficient of variability is a whole number, the proper entry of A in Table 1, or of B in Table 2, is simply divided by the square root of N to obtain the respective error. When the value of C. V. is not a whole number, the proper value of A or B may be obtained by direct interpolation, as shown in examples 2 and 4. The amount of discrepancy between such interpolation and direct substitution in the formulae has been found small enough that only the third place of A or B is affected.

METHOD OF FERTILIZER APPLICATION FOR CANNING PEAS[1]

F. L. MUSBACH[2]

The importance of securing maximum benefits from the use of fertilizers has been given much attention by agronomists in recent years. It is generally admitted that a much larger return in fertilizer investment may be secured by proper placement. In the case of corn and other cultivated crops, placing fertilizers in bands on both sides of the row or hill has been found more profitable in practically every trial reported. This practice is now well nigh universal. In the case of small grains drilling fertilizer down the same spout with the seed has also proved superior to broadcasting. Little or no injury has been reported even with moderately heavy applications.

In the case of peas there is some danger of germination injury due to fertilizers. Particularly is this noted when the crop is grown on drouthy soil, or even on heavy soils with a low moisture level at planting time. Phosphates are generally harmless. Potash in moderate rates may also be used safely. Inorganic nitrogen, however, is likely to cause trouble, particularly on soils of low water-holding capacity or on any soil deficient in moisture during the germination stage.

At the Marshfield, Wis., Station the placement of fertilizer for peas has been studied for 3 years. The soil on which canning peas was grown is mapped as Colby silt loam. The surface 8 inches are a grayish silt loam underlain by a retentive subsoil. It has an excellent water-holding capacity.

THE 1930 RESULTS

Alaska peas were planted May 1, 1930, at the rate of 4½ bushels per acre. The soil contained a normal supply of moisture, averaging approximately 30% computed on the dry basis. On one section fertilizer was drilled with the seed at two different rates, *viz.*, 300 and 500 pounds. On another section fertilizer at these rates was applied directly above the seed separated by 1½ to 2 inches of soil by means of special surface distributors consisting of tubes fastened to the disks of the drill and connecting with the fertilizer hopper. In Table 1 is indicated the effect on yield and on siftings.

The 300-pound application above the seed gave 1,618 pounds of peas per acre, while with the same amount of fertilizers drilled with the seed the yield was increased 146.5 pounds. The 500-pound application above the seed produced 1,838 pounds which in turn was increased 210.5 pounds by applying fertilizer with the seed.

The crop was vined July 7, 68 days after planting, at a stage when the peas were in excellent condition for processing as evidenced by the

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[1] Contribution from the Department of Soils, Wisconsin Agricultural Experiment Station, Madison, Wis. Received for publication March 16, 1933.

[2] Professor of Soils.

high percentage of the smaller sizes. It is apparent that fertilizer applied with the seed served to hasten maturity, particularly the 500-pound rate.

TABLE 1.—*Effects of different fertilizer placements on peas in 1930.*

Rate and method of application	Yield per acre, lbs.	Increase, lbs.	Percentage siftings	
			1's, 2's, and 3's	4's and 5's
300 lbs. 2–16–8 above seed	1,618.0	——	71.9	28.0
300 lbs. 2–16–8 with seed	1,764.5	146.5	69.1	30.9
500 lbs. 2–16–8 above seed	1,838.0	——	77.5	22.5
500 lbs. 2–16–8 with seed	2,048.5	210.5	74.5	25.4

The more advanced maturity was also confirmed by the puncture test (Crowther tester). The average puncture test of 50 No. 4 peas gave the following results:

300 lbs. with seed	420.3 grams
300 lbs. above seed	386.7 grams
500 lbs. with seed	415.1 grams
500 lbs. above seed	392.3 grams

In order to study germination injury due to fertilizers, counts on stand were taken when the crop was well up. Assuming 100% stand on the treatments receiving fertilizers above the seed, counts showed a 90.9% stand where 300 pounds of fertilizer were applied with the seed and 85.8% stand with the 500-pound treatment. In spite of the reduction in stand the application of fertilizer with seed showed an increase in yield over the "above seed" treatment and also served to advance maturity.

THE 1931 RESULTS

The 1931 work involved a study of phosphate, phosphate and potash, and complete fertilizer applied broadcast as compared with drill row applications. A number of preplanting treatments were also included. The season proved an ideal one for studying germination injury because of the abnormally low moisture content of the soil. At planting time the moisture supply on the heavy silt loam was found to be 15.6% on the dry soil basis.

In this experiment drilling fertilizers down the same spout with the seed was studied in comparison with equivalent amounts of the various mixtures applied in a broadcast manner before planting. It has been argued by some that because of the sensitiveness of peas, fertilizers should be applied at some time in advance of planting the crop in order that the "burn" may be taken out of the fertilizers. The two mixtures 0–16–0 and 0–16–8 were applied broadcast and disked in on April 8, a month prior to planting. Alaska peas were drilled May 8 at the rate of 4.5 bushels per acre.

In Table 2 is indicated the yields and the percentage of small and large peas for each of the various treatments.

On account of the low moisture content of the soil at the time of planting the results are interesting in studying effects of fertilizer materials on yield as well as on quality.

TABLE 2.—*Effects of different fertilizer placements on peas in 1931.*

Treatment and method of application	Yield per acre, lbs.	Percentage siftings	
		1's, 2's, and 3's	4's, 5's, and 6's
320 lbs. 0–16–0 drilled	1,625	42.5	57.4
320 lbs. 0–16–0 broadcast	1,502	54.2	45.4
310 lbs. 0–16–8 drilled	1,475	48.1	51.9
310 lbs. 0–16–8 broadcast	1,526	49.1	50.8
330 lbs. 4–16–8 drilled	1,240	44.4	55.5
330 lbs. 4–16–8 broadcast	1,613	46.2	53.6
355 lbs. 4–16–16 drilled	1,171	55.2	44.5
355 lbs. 4–16–16 broadcast	1,468	48.8	48.1
400 lbs. 0–16–0 preplanting	1,491	52.9	46.9
400 lbs. 0–16–8 preplanting	1,507	51.8	48.1

Drilling straight phosphate gave a total yield of 1,625 pounds, representing an increase of 123 pounds above the yield obtained where the same amount of fertilizer was applied broadcast. The effect on maturity is also to be noted. The smaller siftings, Nos. 1 to 3 inclusive, averaged 42.5% and the larger sizes, 4's to 6's inclusive, 57.4%. The broadcast treatments showed a considerable larger proportion of the smaller sizes with a corresponding smaller amount of the large sizes.

The addition of 8% of potash (0–16–8) served to reduce the yield 51 pounds per acre. Germination injury to a considerable extent was responsible since by actual count the stand was cut approximately 20% on the plat where fertilizers were drilled with the seed. The effect on maturity as indicated by the percentage of the different sizes shows a negligible increased maturity in favor of the drilling method.

The addition of nitrogen in the 4–16–8 diminished crop yields materially. The stand as determined by count was reduced practically one-third. The effect on maturity was slightly in favor of the drilled application. Increasing the potash to 16% in the 4–16–16 cut the stand 30% and also brought about a definite delayed maturity largely because of the setback in the earlier period of growth. The yield was also reduced nearly 300 pounds.

The preplanting applications (0–16–0 and 0–16–9) were made at the rate of 400 pounds to the acre. In neither case was there any appreciable difference in yield as compared with similar broadcast treatments at somewhat lower rates applied the same day the peas were planted. From the year's results, therefore, there appears to be no reason why preference should be given to fertilizer applications any length of time in advance of seeding.

THE 1932 RESULTS

Based upon the two years' previous work it appeared that germination injury resulting in a reduction of stand as well as yield is due primarily to the moisture content of the soil at planting time. The amount of rainfall subsequent to planting is also an important factor determining the extent of injury. The work in 1932 was planned with a view of studying this problem further using only two mixtures, 0–16–0 and 2–12–6. These are fertilizers commonly used by farmers for the pea crop. Three different rates of application were studied, *viz.*, 150 pounds, 300 pounds, and 450 pounds. In one set of plats the fertilizer was applied broadcast and disked in before planting and in the other approximately the same rates drilled in with the seed.

Alaskas were planted on May 12 at the rate of 4.6 bushels per acre. In contrast to the 1931 season when the ground was exceptionally dry the soil moisture on the plats this year averaged 36% at planting time. The yield per acre for both methods of application is indicated in Table 3.

TABLE 3.—*Effects of different fertilizer placements on peas in 1932.*

Treatment	Yield of peas, lbs.		Percentage siftings			
			1's, 2's, and 3's		4's, 5's, and 6's	
	Drilled	Broad-cast	Drilled	Broad-cast	Drilled	Broad-cast
150 lbs. 0–20–0	337	258	82	90	18	10
300 lbs. 0–20–0	456	266				
450 lbs. 0–20–0	440	262				
150 lbs. 2–12–6	535	367	84.5	82	15.5	18
300 lbs. 2–12–6	460	434				
450 lbs. 2–12–6	524	332				

The crop, harvested on June 30 approximately 7 weeks after planting was practically a failure as will be noted by the very poor yields. The low yields were due entirely to a very severe infestation of pea aphid. Aphid infestation was noted before the plants were up 4 inches. Although insecticide treatments were used, it was impossible to control the ravages of the pest. Due to the severe injury of the aphid and the short growing season, inferior yields were to be expected.

Applying 0–20–0 broadcast showed little differences in yield for any of the three rates of application. The range was from 258 to 266 pounds per acre. Drilling in the row with the seed showed a marked increase over the broadcast treatment at this stage of maturity, particularly with 300- and 450-pound rates. With the complete mixture, 2–12–6 drilled in the row with the seed, the yield was likewise increased for each of the three rates of application. Whether this trend increase would carry through if the crop were allowed to reach normal canning stage cannot, of course, be predicted from the data available. It is reasonable to suppose, however, that with the start made when the crop was harvested better yields would have been secured on plats where fertilizer was drilled instead of applied broadcast.

Sifting analyses were made only on the crop receiving the 300 pounds of each of the fertilizer mixtures both on the broadcast and the drilled applications. Little significance can be attached to these data. As will be noted 80 to 90% of the total crop graded as 1's, 2's, and 3's representing the smaller sizes. This illustrates quite clearly the immaturity of the crop when harvested.

The degree of fertilizer injury was again determined by counting the number of plants per rod row (average of 10 rod rows). The 150-pound treatment of either the 0–20–0 or 2–12–6 drilled showed no diminution in stand as compared with broadcast applications. The 300-pound and 450-pound treatments of 0–20–0 showed a slight reduction, averaging a trifle over 5%. In the case of 2–12–6 the 300-pound treatment reduced the stand 8.5%, while the 450-pound application was responsible for a 20% reduction. The effect on yield with the 450-pound rate, however, has not been in the direction of lower yield. The plants remaining, by their better growth and increased vigor, were apparently able to overcome this handicap.

A 450-pound application of a mixture such as a 2–12–6 is probably more than can be used profitably by the pea crop, either drilled or broadcast. In this connection a very pertinent question may be raised regarding the rate of seeding peas. It seems quite possible that with moderate fertilizer applications, particularly drilled in the row, the rate of seeding may be reduced in amounts sufficient to absorb at least part of the fertilizer bill and yet secure better yields. This problem is to be studied in the near future.

SUMMARY

The results of 3 years' work show that under normal moisture conditions better yields are secured on silt loams by drilling as compared to broadcasting fertilizers. Smaller rates per acre drilled in will result in as good or better yields than if the same mixture is applied broadcast. In seasons with a low supply of soil moisture, however, care should be exercised as to the kinds and amounts of fertilizer used. On light sandy soils which are, of course, not adapted to pea growing anyway, losses due to germination injury are more likely where fertilizers are drilled in the row.

On average silt loam soils, where the bulk of the peas are grown in Wisconsin, and under normal weather conditions, it is safe to drill with the seed 250 to 300 pounds of 20% superphosphate and approximately the same amount of complete fertilizer relatively low in nitrogen, such as a 2–12–6 or a 2–16–8. Even though some reduction in stand results, the increased vigor of the surviving plants and the better filling of the pods will result in larger acre yields. It is also apparent that maturity is hastened, a factor of some importance in producing quality peas.

NOTES

AN INEXPENSIVE LYSIMETER

A study has been started at the Kentucky Agricultural Experiment Station on the effect of Kentucky bluegrass and certain legumes, grown separately and together, on soil nitrogen economy. It was thought desirable to determine nitrogen leaching. Inexpensive lysimeters were constructed for this purpose. Details of one of these are shown in Fig. 1.

They were made from ordinary 55-gallon steel drums. The drainage water collecting in the reservoir in the lower part of the drum is removed by connecting the water removal tube to a bottle and partially exhausting the air in the bottle. The cover for the reservoir, which also is the bottom of the soil-containing part of the lysimeter, is made from the removed top of the drum. It is supported by the wall of the reservoir and by a small concrete column in the center of the reservoir. Small holes in this cover permit drainage.

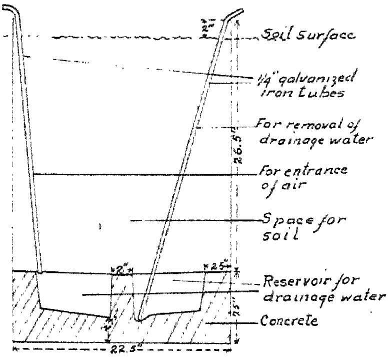

FIG. 1.—Vertical center cross section of a lysimeter made from an ordinary steel drum.

The cost of making and installing 22 of these lysimeters, using the soil to fill them which was removed from the openings where they are placed, was about $130.00.—P. E. KARRAKER, *Kentucky Agricultural Experiment Station, Lexington, Ky.*

A SIMPLE SOYBEAN SEED COUNTER

In conducting germination and other important tests where seed counting is essential, a simple, quick yet accurate mechanical counter is almost imperative. Such a counter has been devised by Claude Greenham of the Agronomy Department at Purdue University Agricultural Experiment Station. The Greenham soybean seed counter, as shown in Fig. 1, was made from a piece of ½ inch planed walnut lumber cut 6¾ x 5⅜ inches in size. One hundred holes, equally spaced ⅝ inch from center to center were then bored into one surface by means of a ⅜ inch reamer. The holes are 2/8 inch deep and taper to a point at the bottom. A hole of this size and shape will accommodate the seed of most soybean varieties. The corners of the edges of the counter were rounded so as to permit easy operation when taking samples. This type of counter can easily be adapted for counting other seeds, especially the larger, more globular shaped ones.

The Greenham counter is quickly and simply operated. By repeated tests it has been shown to be capable of counting 10 times as fast as the average person can count. Furthermore, when the counting is done, it is correct since only one seed can lie in each of the 100 holes. On the other hand, the seeds counted by the average person may, or may not be correct.

The counter is used in the following manner: Place a small quantity of seed from which samples are to be taken in a shallow container. The counter is then held by the left hand so that it will lie as flat as possible on the surface of the seed and with the right hand the seed is pulled over the counter until it is completely covered. The counter is then agitated slightly and tilted sufficiently to allow those seeds lying between the holes to roll off leaving each of the 100 holes occupied by a single seed. This operation is again repeated until the requisite number is secured.—G. H. CUTLER, *Department of Agronomy, Purdue University, Lafayette, Ind.*

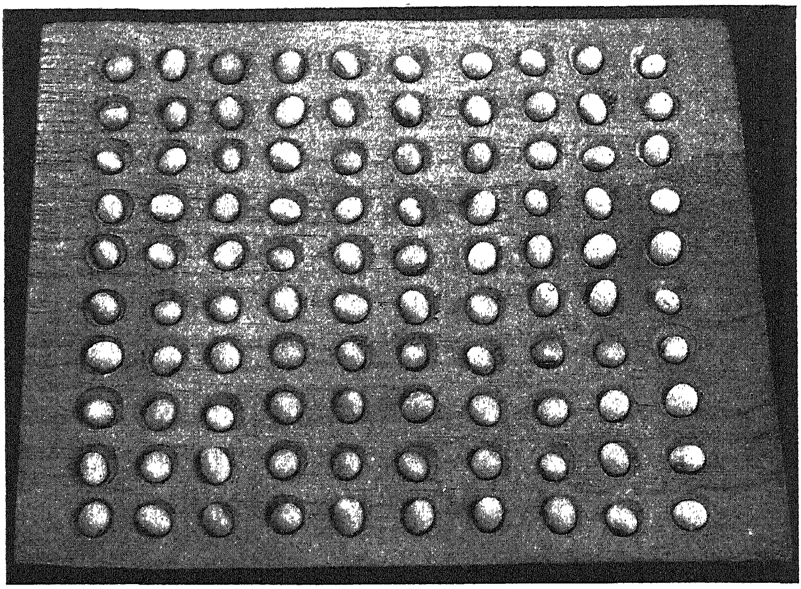

FIG. 1.—The Greenham soybean seed counter.

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MINUTES OF THE 1933 BUSINESS MEETING OF THE SOILS SECTION

The first regular meeting of the Soils Section of the American Society of Agronomy was called to order at 1:45 P. M., November 16, 1933, in the Stevens Hotel, Chicago, Ill., by Chairman Richard Bradfield.

No unfinished or new business was presented and the Section proceeded to the election of officers. The Nominating Committee placed Professor C. F. Shaw in nomination for Chairman and Dr. W. A. Albrecht for Secretary. There were no nominations from the floor, and Professor Shaw and Dr. Albrecht were elected without dissenting votes. The meeting was then adjourned.

C. E. MILLAR, *Secretary*

MEETINC OF AMERICAN MEMBERS OF INTERNATIONAL SOCIETY OF SOIL SCIENCE

Immediately upon adjournment of the Soils Section of the American Society of Agronomy on November 16, 1933, in the Stevens Hotel in Chicago, Ill., a meeting of the American members of the International Society of Soil Science was called, with Dr. A. G. McCall presiding as American representative of the Society.

Dr. McCall raised the question of payment of dues to the Secretary, Dr. Hissink. It has been the custom for American members to forward their checks for dues to Dr. McCall, who in turn forwarded the money to the International Secretary. The constitution states that dues paid to Dr. Hissink shall be equivalent to 10 Dutch gilders. Inasmuch as the rate of exchange is now in favor of the Dutch gilders, it requires considerably more than $4 to cover the dues, and the amount needed is more or less fluctuating. Under the circumstances, Dr. McCall proposed that he return checks now in his hands to those who had forwarded them to him and that each member pay Dr. Hissink directly through a postal money order equivalent to 10 gilders. A motion to this effect was made by Dr. Kellogg and was carried.

Dr. Bradfield discussed the relation of the Soils Section of the American Society of Agronomy and of the American Association of Soil Survey Workers to the International Society of Soil Scientists. In order to determine what group of soils workers in America shall constitute the American Section of the International Society of Soil Science, Dr. Bradfield moved that a committee consisting of the Chairman and Secretary of the Soils Section of the American Society of Agronomy, the President and Secretary of the American Soil Survey Association, and the Past-President (Dr. J. G. Lipman) and the American Secretary of the International Society of Soil Science be requested to examine critically the Constitution and By-Laws of the Soils Section of the American Society of Agronomy and recommend such changes as seem desirable in order to provide as follows:

1. For a single association of soil scientists, organized on a sectional basis similar to the International Society of Soil Science which shall function as the American Section of the International Society of Soil Science.

2. That the desirable features of the present associations be preserved in so far as it is possible.
3. That a copy of the recommendations of this joint committee be sent to (1) every member of the International Society of Soil Science in America, (2) every member of the American Soil Survey Association, (3) every member of the Soils Section of the American Society of Agronomy, and (4) every member of any other large organization of soil scientists in America which the committee desires to consider, not later than September 1934.
4. That the recommendations of this committee be considered first at a meeting to which all persons interested in soil science are invited to participate, such meeting to be held in Washington, D. C., at the time of the 1934 annual meeting of the American Soil Survey Association and the American Society of Agronomy.
5. That the final form of the recommendations adopted by this joint session be referred to the separate organizations for ratification.

The motion was seconded by Dr. Kellogg. Dr. Marbut moved that the motion be amended to include the statement, "That the integrity of the present soil organizations be maintained." This was seconded by Professor Wiancko. After considerable discussion, the motion was lost. Mr. Ellis of Manitoba suggested that the Canadian members of the International Society be affiliated with the United States group as the American Section. The original motion was carried. Meeting adjourned.

C. E. MILLAR, *Secretary*

A GREETING FROM RUSSIA

Immediately upon recognition of the Soviet Government by the United States, Dr. Richard Bradfield, in his capacity as Chairman of the American Section of the International Society of Soil Science, received the following cablegram from Professor Yarilov, Chairman of the Organizing Committee of the International Congress of Soil Science:

> Soviet Section of I. S. S. S. send American Section warmest greetings. Best wishes for still deeper scientific connections based on reapproachment of greatest world Republics.—Yarilov.

Dr. Bradfield replied as follows:

> American pedologists hope now for even more inspiration from their colleagues in U. S. S. R.—Bradfield.

NEWS ITEMS

PROFESSOR WILLIAM B. COBB of North Carolina State College died in Chicago shortly after the annual meeting of the Society in that city in November. He was taken ill during the meetings and succumbed to pneumonia a few days later. Professor Cobb had been an active member of the Society for several years and at the time of his death was a member of the Committee on Soil Erosion.

DR. H. L. WALSTER, Dean of the School of Agriculture and Chairman of the Department of Agronomy, North Dakota Agricultural

College, was recently named Director of the Agricultural Extension Service of the College, and on July 1 will succeed to the Directorship of the Experiment Station.

THE ORGANIZING COMMITTEE for the Sixth International Botanical Congress has decided that the 1935 Congress shall meet in Amsterdam, Holland, September 2 to 7.

P. J. OLSON, assistant plant breeder in the Department of Agriculture of the North Dakota Agricultural Experiment Station, has been elected assistant Dean of the Division of Agriculture, and assistant Director of the Experiment Station. Mr. Olson has already assumed the assistant Deanship and will take over the assistant Directorship of the Experiment Station on July first.

DR. E. G. BOOTH, extension agronomist of the North Dakota Agricultural College, and G. N. Geiszler, assistant in plant breeding in the North Dakota Experiment Station, have been loaned to the Federal Land Bank of St. Paul up to July 1, 1934.

WM. WIIDAKAS has been appointed an assistant in the Department of Agronomy in the North Dakota Agricultural Experiment Station.

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A SYMPOSIUM ON "MAINTAINING THE EFFICIENCY OF AGRONOMIC RESEARCH WITH REDUCED SUPPORT THROUGH REGIONAL ORGANIZATION"

EDITOR'S NOTE.—The three papers which follow were presented upon invitation of President M. A. McCall before a general session of all Sections of the Society at the annual meeting in Chicago, November 16, 1933. The Executive Committee requested that they be assembled and published in an early number of the Journal.

1. REGIONAL COORDINATION OF AGRONOMIC RESEARCH FROM THE STANDPOINT OF THE STATION DIRECTOR[1]

L. E. CALL[2]

I have been asked by the President of this Society to discuss briefly regional coordination in agronomic research from the standpoint of the administrator. As a background for this discussion, permit me to recount briefly the manner in which research in agronomy has developed.

Agronomic research had its beginning as independent isolated bits of investigation that were undertaken to solve local problems. The work was frequently started without consideration as to what was being done elsewhere and without thought of coordinating the work as a unit in any carefully planned project of a national or regional application. This is the normal development in any young branch of science. It is most logical that agronomic research should have developed in this way.

There came a time, however, after a certain amount of progress had been made when it became evident that work conducted in this manner led to much wasteful duplication of effort, and that future progress required closer cooperation among the workers and greater coordination of the work. Thus, there has gradually developed an increased interest in cooperation among the workers in closely related fields of agronomic research and in an effort to coordinate the work.

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[1] Contribution No. 51 from the Office of the Director, Kansas Agricultural Experiment Station, Manhattan, Kan.

[2] Director.

The various bureaus of the U. S. Dept. of Agriculture in their cooperation with the state stations took the leadership. They built upon a national and regional basis a number of projects of cooperative investigational work. This marked the beginning of carefully planned coordinated agronomic research. Among the projects where work was coordinated in this way may be mentioned the cooperative soil survey between the Bureau of Chemistry and Soils and many of the states throughout the United States, the cooperation of the Bureau of Plant Industry with the states in plant breeding and cereal variety testing, in winter hardiness studies of winter wheat, in dry-land investigational work in the Great Plains, in grass and forage crop studies, and in numerous other phases of agronomic research.

This work also initiated an effort upon the part of agronomy workers themselves to cooperate. The effort has been outstandingly successful. While it was undertaken with the full knowledge and approval of the officials administering the work and frequently under memoranda of understanding approved by them, there has been little or no effort upon the part of such officials to do more than offer constructive suggestions as to the work undertaken or the manner of its execution. In other words, such coordination as was brought about was initiated by the workers in the field of agronomy themselves, not by administrative officials.

The first formal effort upon the part of administrative officers to set up coordinated research projects came as the result of the passage of the Purnell Act. Following the passage of this Act, the agricultural experiment station directors and U. S. Dept. of Agriculture administrative officials meeting at St. Louis in 1925 made plans for starting a number of fundamental investigations of a national character that might be attacked cooperatively by the various agricultural experiment stations and by the federal Department of Agriculture. Among the projects approved at that time was the Purnell corn breeding project to be conducted cooperatively between a number of corn belt states and the Bureau of Plant Industry of the U. S. Dept. of Agriculture. Thus for the first time in agronomy a well-directed effort toward coordination was initiated by those directing the work rather than by those doing it. While the national Purnell projects were initiated by administrative officials, no effort was made by those officials more than to suggest in the broadest way the phases of the project to be attacked by the different cooperating agencies or the manner of the attack.

Undoubtedly, the most formal effort that has been made by administrative officials to coordinate research in any region has been made by the directors of the northeastern agricultural experiment stations of the United States.[3] Meeting annually as they have for many years, they have appointed from among their members referees from time to time to study the need for research in different fields and to suggest new lines of research that should be undertaken. Through conferences of research workers in the different subject matter fields cooperative projects have been formulated with specific phases of work assigned to the different workers at the different stations. While much of the work in this section, undertaken in this way, has been outside the field of agronomy, a number of agronomic projects have received consideration. Examples are pasture investigations and soil organic matter studies.

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[3] Slate, W. L. Coordination in research between states in the northeastern states. Proc. 46th Ann. Conv. Assoc. Land-Grant Col. and Univ., 261–264. 1933.

This brief account of the trends in the development of agronomic research clearly indicates that the need for closer coordination has been recognized both by the research workers and those administering research, and that while the first steps toward coordination were taken by the workers themselves, there has been a growing tendency upon the part of those administering research to shape administrative policies so as to make coordination more certain.

The indisputable fact that there is a more definite trend toward coordination in agronomic research and that this trend is being encouraged by both research workers and administrators raises a number of pertinent questions among which are the following:

1. Should further coordination in agronomic research be encouraged?
2. What are the advantages?
3. What are the disadvantages?
4. Do the advantages outweigh the disadvantages?
5. What type of research problem lends itself to coordinated attack?
6. Are all research workers able to adjust themselves and their work to a coordinated program?
7. What characteristics should a research worker possess to enable him to cooperate best in a coordinated research program?

POSSIBLE ADVANTAGES OF COORDINATED RESEARCH IN AGRONOMY

The rapidity with which cooperative research in agronomy has developed among the workers and the extent to which it has been encouraged by administrators is ample evidence that there is merit in this manner of attacking certain agronomic research problems. Perhaps some of the more obvious advantages are the following:

1. It reduces or prevents unnecessary duplication of work.
2. It makes possible a comprehensive and well-rounded attack on intricate problems.
3. It eliminates artificial political boundaries in attacks on both national and regional problems.
4. It promotes generalization over a wide area in the interpretation of results.
5. When properly administered, it raises the morale and esprit de corps of the workers and encourages personal contacts and the exchange of ideas.

In these days of reduced budgets, when it is next to impossible to secure the funds with which to finance the most urgent and essential phases of work and when expenditures must be held to the minimum, the advantage from coordination that appeals most strongly to the administrator is the financial saving that may result from coordinated attack on research problems. Quite as important, however, is the saving in time and effort on the part of the workers themselves by the elimination of unnecessary duplication. Two or more persons working on the same or closely related problem will usually duplicate unnecessarily the work of each other. While duplication from the standpoint of checking accuracy of results is desirable, greater duplication than is necessary for this purpose is indefensible.

Some of the best examples of coordination to prevent unnecessary duplication have been those phases of research in which there has been an outstanding worker who has been able because of his recognized standing to dominate the field of study and to secure the cooperation of other workers, and by mere suggestion to induce them to attack different phases of the problem in need of further study. In this way undesirable duplication has sometimes been avoided and excellent coordination of research effort secured. Such leaders, however, are rare. I shall not attempt to name any. Undoubtedly each of you, however, can name at least one individual who in your judgment has been of unusual service in this way. In the past the services of such natural leaders have not been utilized to the extent that would be desirable. They have had no authority to assume leadership in coordinating the work in their field of study. Moreover, they usually have been busily engaged upon a full-time research program of their own. There is need from an administrative standpoint of an arrangement whereby such men may be relieved in part from their regular duties and given an opportunity, perhaps through the U. S. Dept. of Agriculture, to spend at least a part of their time visiting other workers and helping by suggestion to coordinate the problems of these workers into a well-rounded research program. It is not my thought that such leaders would have power to direct but rather that they would accomplish their purpose in so far as possible merely by suggestion.

Many of the problems upon which agronomists are working today are much too intricate to yield to solution as the result of the effort of a single individual who at best is trained to attack the problem from one point of view only. Difficult problems are seldom solved in this way. They usually yield to solution only when attacked from different angles simultaneously by workers with different viewpoints trained in different fields of work. Coordination of research effort should extend, therefore, beyond the agronomist. It should enlist the cooperation of research workers in other closely related fields. The assistance of entomologists, plant pathologists, physiologists, ecologists, chemists, physicists, and many others is essential. Thus the intricate unsolved problems confronting agronomists today will be solved most successfully not only by the coordination of the efforts of agronomists themselves but by the cooperation of those trained in other fields cooperating with agronomists.

Not the least advantage of coordinated effort in the attack on agronomic problems is the opportunity that a proper plan for coordinating the work affords for personal contacts and the exchange of ideas among those working along the same line. In addition to raising the quality of the work by these contacts, the enmity and jealousy between workers tends to be broken down and the morale and esprit de corps of the entire group of workers are raised.

POSSIBLE DISADVANTAGES OF COORDINATED RESEARCH IN AGRONOMY

Not all factors are favorable to coordinated programs of research in agronomy. There are disadvantages, among which the following are perhaps the most obvious:

1. It may tend to limit the individuality and initiative of the investigator.
2. It may become too mechanical.
3. It offers the temptation of over-organization to over-zealous administrators.
4. It presents the difficulty of finding project leaders and workers with a unique combination of those rare but indispensable qualities necessary for successful cooperation.
5. It may lead to excessive travel and loss of time on the part of workers attending conferences and observing the work of other agronomists.

Many able research workers do not possess those characteristics which enable them to cooperate successfully with other workers. To attempt to force such workers into a coordinated research program would not only prove most distasteful to them but would undoubtedly result in a marked decrease in their efficiency and might prevent the accomplishment of what would otherwise have been valuable results. The majority of outstanding contributions to science have been made in the past by individuals, not by cooperating groups. The contributions of such men as Darwin, Pasteur, Mendel, Faraday, and Newton were highly individualistic. It would be difficult to imagine the work of such men being accomplished through a coordinated research program. It may be stated perhaps as a generalization that fundamental principles usually have been discovered by men working alone, while where practical applications are to be made, as is the case with much agronomic research work, cooperation may be extremely helpful.

The personality of the individual as well as the character of the work to be undertaken will have an important bearing on the success of coordinated research effort. Some of the most competent investigators chafe under direction and render their most valuable contributions when working entirely alone. On the other hand, there are those lacking vision and initiative who must have constant guidance and direction and who are productive only when at work under close supervision. Most workers occupy the middle ground between these two extremes and render most efficient service when working in a coordinated program under the direction of competent leaders who have both vision and tact.

It seems to me that a careful weighing of the advantages and disadvantages of coordination in attack on agronomy research problems leads to the conclusion that the manner of attack will depend (1) upon the type of problem to be studied, and (2) the personnel involved. Since many agronomic problems both in crops and soils appear to be uniquely suited to coordination in method of attack, it is reasonable to expect that an increasing amount of the work of the future may be undertaken in this manner. The matter, therefore, of satisfactory personnel to conduct coordinated research becomes of increasing concern to the administrator.

WHAT CHARACTERISTICS SHOULD THE WORKER POSSESS WHO IS BEST QUALIFIED TO WORK ON A COORDINATED RESEARCH PROJECT?

As has been pointed out, not every research worker is fitted temperamentally to engage in cooperative research. Some of the very best trained workers belong to this individualistic class. These workers can be put to work most satisfactorily on problems of a fundamental character. On such work their contributions may be as great or greater than the contributions of those men more cooperative minded. A proper proportion of such workers can be used effectively upon the staff of most research agencies, especially those of considerable size. Such individuals will be of little use, however, when coordinated research is to be undertaken.

What qualifications should be possessed by the others who are to be assigned to cooperative research problems? Taking for granted that all research workers will be thoroughly and fundamentally trained for the work in which they expect to engage, there are several other characteristics that I consider highly essential for successful cooperation. These characteristics are as homely as they are rare. Some of them are the following:

1. *Willingness to give and take.*—The ability to cooperate successfully requires that the worker be willing to give about 90% of the time and to expect to take about 10%. It is only when cooperative research is entered into in the spirit that the worker will give everything that he possesses of ability and knowledge freely to his coworkers that the fullest measure of success can be attained. Any lack of willingness to give retards the success of the project in proportion to the extent that full cooperation is withheld. It is probably safe to assume that everyone is intrinsically selfish to a greater or less degree, that we are often motivated in what we do by selfish desires, and that human nature is not easily changed. Can we expect to find, therefore, workers who will give in what appears to be superficially so unselfish a manner? A more careful consideration reveals that those workers who give in this manner may not be actuated by wholly unselfish motives because it is clearly evident that in the end those individuals profit most who through so-called generosity contribute most freely to cooperative work. By doing so, outstanding accomplishments are attained and all profit. It seems to me that those individuals who exhibit the greatest degree of short-sighted selfishness are those who refuse to cooperate wholeheartedly and by so doing retard the advancement of the group and incidently their own progress. In looking for those who are willing to give and take I am not looking, therefore, for unselfishness but rather for a form

of selfishness so highly developed that the individual recognizes that his own welfare is dependent upon the welfare of the group whether that group be the members of his office, department, station staff, or the entire fraternity of workers with whom he has cast his lot. Unless and until this self-evident fact that the best interest of the group is the best interest of the individual is recognized by all workers cooperating on a project, it will be impossible to attain the fullest meassure of success in coordinated research.

2. *Ability to see the other fellow's point of view.*—Many of the difficulties that arise in the conduct of cooperative work result from the inability of one worker to attain fully the point of view of another worker. The ability to see the other fellow's point of view is a quality that is developed through a sympathetic understanding of the work of others and comes from intimate acquaintance and a sincere desire to help. It cannot always be obtained because the other fellow's view-point is not always correct, but it should be approached with the attitude of mind that perhaps after all the other fellow is right and I am wrong.

3. *Not having an undue concern for personal credit.*—Perhaps the one stumbling block that most often stands in the way of successful cooperation is the fear upon the part of workers that full credit will not be obtained for their accomplishments. It is usually a needless fear. There have been some cases where deserving research workers engaged in a cooperative project have not been given adequate credit by their superiors or co-workers. Seldom, however, has this prevented proper recognition coming in the end to the person who did the work. It is not always necessary for the name of the worker to appear on the published manuscript in order that credit be obtained. There are many other ways in which the knowledge of creditable accomplishments receive public recognition. Any research worker in agronomy can enter wholeheartedly into cooperative research work without undue concern as to the credit he will receive. It has been my observation that those most concerned about proper credit are the ones with least credit due them about which to be concerned.

CONCLUSIONS

In conclusion, it seems evident that the trend of the past toward cooperative research in agronomy will continue and that more rather than less of the work will be conducted upon a coordinated basis. Independent work will continue. Perhaps most of the more fundamental work will be done in this way, but those phases of investigation, involving work that has practical application over a considerable area, and this makes up the major portion of agronomic research, will be organized more and more upon a cooperative basis and conducted as coordinated research. The rapidity with which coordination develops will depend upon the ability of those administering it to secure competent leaders for cooperative projects and to develop personnel who have those qualities essential for cooperation, such as willingness to give rather than to take, ability to see and appreciate the other worker's point of view, and lack of undue concern about personal credit for work done.

Workers in agronomic research who possess these characteristics will be in increasing demand in the future and as workers with these characteristics are developed or obtained, an even larger amount of research in agronomy will be organized on a well-developed and coordinated basis.

2. REGIONAL COORDINATION OF AGRONOMIC RESEARCH FROM THE STANDPOINT OF THE CROPS INVESTIGATOR[1]

H. K. HAYES[2]

Cooperation and coordination are major methods now being used by our federal government in an attempt to overcome the many difficulties facing the individual worker in nearly all walks of life. It is yet too soon to determine the extent to which the NRA, AAA, and other programs will solve our present economic chaos. On every hand, however, there is continued optimism, and the people, by and large, have expressed their approval of the attempt by the government to adjust and coordinate the opportunities of individual workers.

At a time when coordination is being used so widely in every phase of our reconstruction program it is logical for our Society to consider the question of greater coordination in research as a means of maintaining or increasing our efficiency. This subject is a natural one for our President to suggest, as regional coordination in the past has been aided materially by cooperation between investigators from the Office of Cereal Crops and Diseases and workers at many of our state experiment stations. While emphasizing the interest of our President in greater regional coordination, I shall endeavor to show that state investigators are equally ready to join in regional coordination, providing such coordination can be arranged without interfering with the initiative and enthusiasm of the individual investigator.

It is possible to define regional coordination in various ways. Some would believe that it requires a coordinator or single unselfish leader to direct the program. Others believe coordination can be obtained through the efforts of the workers and by means of group contacts. Dictionary definitions of coordination are as follows: (1) "State of being coordinate or of equal rank, dignity, etc.", (2), "Act of combining to give harmonious results." The definition of coordination that I wish to use for the purposes of this discussion requires that coordination be accomplished without limiting individual initiative. I shall, therefore, define regional coordination in agronomic research as follows: To join in a regional attack on agronomic problems for the purpose of obtaining harmonious results and without interfering with the dignity, initiative, or "academic freedom" of the individual worker.

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[1] Contribution from the Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1229 of the Journal Series, Minnesota Agricultural Experiment Station.

[2] Chief, Department of Agronomy and Plant Genetics.

In the development of this subject it is my hope to outline the present status of regional coordination and summarize the opinions of individual investigators in the Corn Belt regarding the desirability of greater regional coordination than we now have. The discussion has been developed from the standpoint of the individual actually doing the work.

SOME ILLUSTRATIONS OF THE VALUE OF REGIONAL COORDINATION

During the last 20 years the value of cooperation has been recognized rather widely by individual workers and much progress in regional coordination has resulted. In the early days of agronomic research in each state there were only one or two individuals who were responsible for developing crops research within the state and the problem of regional coordination within state borders was not faced. At present in crops research there may be several departments at each experiment station working on similar problems and in many states branch stations may each have their own research projects. In some cases close regional coordination within state borders has been affected. In other and perhaps most cases there is still room for improvement. I shall describe cooperation in crops research at Minnesota illustrating the methods used to bring about closer coordination.

THE MINNESOTA METHOD OF COORDINATING CROPS RESEARCH

The field facilities for agronomic research at Minnesota consist of a central station with branch stations in various sections of the state where regional problems can be solved most logically. While the branch stations are under the same administration as the central station, the subject matter departments at the central station do not have charge of work at the branch stations except through formal or informal cooperation. This may be a wise procedure, for it has resulted in close cooperation between the central and branch station men in carrying out our crops research program.

One illustration of the lack of coordination in the early days may be given. Varietal trials have an important place in a crop improvement program and the determination of varieties that should be tested should be jointly arranged by the central and branch station men. A uniformity of recommendation of varieties by investigators and county agents could not be achieved without mutual effort. In the past there was, in some cases, a wide difference between varietal recommendations of investigators at the branch and central stations. In other cases the necessary trials to determine the value of some promising variety were not made.

Rather close cooperation between investigators in crops has been developed gradually and the method used may be of value in pointing one way toward greater regional coordination between states.

A realization of the lack of coordination of effort by central and branch station men in Minnesota led to an annual conference at University Farm. For the first year or two broader questions of policy were discussed rather frankly. At present and for several years previously smaller group conferences have been held. For the crops research group this meeting consists of all investigators working on crop problems at the central and branch stations. A summary of the year's results is presented at the conference and plans for future work are made. The agronomists and superintendents of the branch stations emphasize the needs for their various regions. Questions of general policy are decided by actual vote of the conference. A recommended list of varieties and their particular region of adaptation is drawn up for publication each year. In order to become a candidate for this recommended list a variety must have been tested for at least a 3-year period and each recommended variety must be approved by actual vote of the conference.

Thus an annual conference of investigators has led to close coordination in crops research. The results achieved have been obtained in a natural way without the necessity of regulations by administrative heads. A mutual feeling of respect among individual workers has developed. In many cases regional coordination can be brought about by such a conference, and in case some one worker refuses to cooperate, his viewpoint can be modified in some instances as he comes to appreciate the sincerity of his fellow workers, or if he seriously lacks a cooperative spirit this becomes apparent also and the administrative leaders can take whatever action they may see fit. Outstanding research men, in my opinion, should not be forced against their will to join in a program of closer regional coordination.

In a somewhat similar manner subject matter divisions within a station may join in a cooperative attack on the same problem. Thus, at Minnesota the Departments of Agronomy and Plant Pathology have joined in an attempt to breed disease-resistant varieties of many of our crop plants. This cooperative program has not limited the initiative of the individual worker. It has required, however, a joint plan and in many cases a division of labor. Much has been gained by this cooperative attack on problems of disease resistance and coordination of effort has been one result. In one visit to another state, I observed three separate disease nurseries for a single crop, each entirely independent of the other. Coordination then in some cases may reduce the cost of obtaining results.

In other cases a coordination of effort may make it possible to solve more easily individual problems. In a wheat breeding program it is of distinct advantage to combine the knowledge of several workers in a joint attack on the problem. The breeder, the cereal technologist, the plant physiologist, the plant pathologist, and the soils investigator may each undertake some phase of a specialized program without loss of individual initiative and with great benefit to the research.

FEDERAL WORKERS AS COORDINATORS

Government workers, in the past, have in many cases aided in regional coordination. They have a major interest in regional problems and the necessary travel funds. Several major cooperative problems have been undertaken by Government and state workers.

One or two illustrations will be given. The spring wheat breeding program for North and South Dakota, Montana, and Minnesota has been developed cooperatively with the Office of Cereal Crops and Diseases. Similar varieties have been grown in 1/40 acre plat trials, in rod-row trials, and to a more limited extent in disease gardens. The results of these trials have been summarized. The greatest limiting factor in the success of this undertaking, in the opinion of the author, is the infrequency of contact between individual investigators. Coordination, without loss of individual initiative, will not be achieved easily unless there is opportunity for the individual workers to get together for a sufficient length of time so that adequate discussion of the results is made possible.

A coordinated program of flax improvement in these same states in cooperation with the U. S. Dept. of Agriculture has been carried out for several years. A part of the funds for flax research was obtained originally from the commercial industries. Unselfish effort is an essential of successful cooperation. This is extremely difficult when the amount of support for each worker is determined on the competitive basis. In spite of this obstacle the cooperative flax program has been highly successful.

THE CORN PURNELL PROGRAM

Several who replied to my questionnaire mentioned the Corn Purnell Program as an illustration of successful coordination of a regional program, and I concur in that opinion. The directors of the Corn Belt stations in 1925 accepted corn improvement as a major regional program under the Purnell Act. A committee of investigators drew up a program of corn improvement under the Purnell Act that was published in our JOURNAL for September, 1926. This program outlined in a broad, direct way the scope of the necessary investigations. It was pointed out that rather free exchange of material and ideas already existed among corn investigators. The value of contacts among investigators was emphasized, as the committee believed group meetings would lead to closer coordination. The following recommendation is quoted from this report:

"The committee feels that everything possible should be done to promote this personal cooperation, as this appears to be the best method of coordinating the program as a whole. With this in mind they recommend strongly that travel, necessary to an annual conference of the workers interested, be recognized as an integral part of the program and that specific provision for such travel be budgeted out of Purnell funds.

"At such meetings, a report of the results of the season's investigations should be presented and discussed. Contemplated new research should be outlined. This would provide for voluntary cooperation and coordination."

Such annual conferences were held each year until recently. An executive committee of five members was elected annually by members of the conference to act in an advisory capacity, when requested, and to arrange for the yearly conference.

Mimeographed reports were furnished each year to individual workers and station administrators. These reports contained summaries of the work at various stations.

The essentials of this program appear to be a project outline, a yearly conference of workers to discuss results and methods of attack, and a summary of the outstanding accomplishments. Such contacts led to a free exchange of material and the development of a cooperative spirit. Coordination was not forced but came about naturally. Each individual worker carried out his own phase of the studies according to the plan that seemed to him most desirable.

COOPERATION IN CORN GENETICS

For many years there has been informal though rather close cooperation between the various workers in corn genetics. This has developed naturally with Dr. R. A. Emerson of Cornell University as the recognized leader. The workers have met informally during the week of the American Association meetings or at other times and have developed a close spirit of cooperation. There has been a free exchange of material and in recent years an annual summary of linkage results has been drawn up, mimeographed, and sent to other workers by Dr. Emerson and his co-workers. It is probable that this cooperation has been aided materially by the fact that a considerable proportion of those engaged in corn genetics are former students of Dr. Emerson.

At present Dr. Emerson is in the process of preparing for publication the present status of the corn linkage problem. In many cases the unpublished data of other investigators have been furnished for this report.

Recently, the Division of Biology and Agriculture of the National Research Council has expressed its approval of the recommendation of its committee in agronomy that assistance be provided for the cooperative corn genetics work. This will make it possible to keep a permanent record and seed of new characters as they are obtained. Investigators will be aided in obtaining special tester strains and by these and other methods close coordination will be accomplished.

OPINION OF OTHERS

A brief questionnaire was sent to men engaged in crops research at various Corn Belt stations to obtain a cross section of opinion regarding the value of greater regional coordination.

The first question—Would greater coordination be of advantage in your program of crops research and experimentation—was answered in the affirmative by 29 of the 33 who replied. Two believed there was some room for expansion and two others doubted the advisability in their researches of greater regional coordination.

Answers to the second question—What are some of the difficulties of greater regional coordination—are not so easily summarized. Eleven of the 33 replies emphasized the difficulties of making the necessary contacts primarily because of the expense of travel. Several emphasized the possibility of coordination leading to less individual freedom and the curtailment of initiative. One or two thought coordination would require a coordinator and doubted the possibility of finding a man with sufficient knowledge, unselfishness, and tact to head up such a program. Two out of the 33 saw no major difficulties. Several emphasized the fact that in the past some of the greatest advances in science have been made by individual workers without cooperation or coordination of any kind. While this is true, the writer wonders if coordination would necessarily limit the outstanding capabilities of the original worker or might sensible coordination lead to a wider and more rapid use of the new principle.

A third question—What would be some of the advantages of greater regional coordination—led to six replies that more rapid progress would be obtained. Several thought coordination would lead to a more critical analysis of the results. Others believed that contact between individuals was the chief advantage to be gained, while several emphasized the possibility that each investigator would be faced with fewer problems. As one investigator aptly stated it, "State boundaries seldom limit the importance of research."

A fourth and final question—Mention some problems that would be benefited by closer regional coordination—gave an extensive list, including breeding problems with all of the major crops, ecological problems relating to the adaptation of crops, cultural problems and methods of weed control, in fact most problems of general interest that engaged individual investigators.

If these summary statements represent the consensus of opinion of men engaged in crops research, it would appear that greater regional coordination could be achieved if the directors of our stations would approve the use of a sensible amount of funds for the necessary travel to establish contacts, attend annual conferences, and make the necessary plans. Speaking as an investigator who must act also in the capacity of administering funds, I should be glad to see several hundred dollars of our rather meager and greatly reduced budget set up as a travel fund to make possible greater regional coordination between states and by means of group contacts.

SUMMARY

Regional coordination in crops research has been developed rather extensively in recent years, although there is room for greater expansion. Investigators in crops are ready for greater regional coordination, providing this can be accomplished without loss of initiative by the individual worker. The consensus of opinion favors the development of greater regional coordination through wider group contacts, the greatest primary difficulty of making the necessary contacts being the lack of travel funds available, this difficulty being greater for state than for federal workers.

There are no *major* difficulties, from the standpoint of the individual investigator, of bringing about greater regional coordination in crops research. Crops investigators in the Corn Belt are almost unanimous in their opinion that such coordination would aid materially in maintaining and increasing our efficiency.

3. REGIONAL COORDINATION OF AGRONOMIC RESEARCH FROM THE STANDPOINT OF THE SOILS INVESTIGATOR[1]

Robt. M. Salter[2]

Coordination, correlation, cooperation—for half a century these three words have permeated the atmosphere of almost every conclave of workers in agricultural science. Forty-six years ago, at the first meeting of the Association of American Agricultural Colleges and Experiment Stations, Dr. W. O. Atwater read a paper on "Coordination in Experimentation' in which he pointed to the desirability of ascertaining "in what ways the different stations may advantageously avoid repeating work which has been done, or is to be done, by other stations, or may cooperate in the study of problems of common interest." A committee assigned to study the question in its report made several suggestions that are as pertinent today as they were in 1887. For example, freedom of action was considered one of the first conditions of such coordination, but ways should be developed for stations to unite in studying specific questions. Quoting directly, "Stations that are to work in dairying may well consult together and seek counsel of specialists in their selection of questions and the methods for their study. The same will apply to those who are interested in feeding, fertilizing and so on, through the list of the more general subjects of inquiry." Very wisely the committee expressed the view, "the most effective and useful coordination and cooperation will come from mutual consultation." High were the hopes of this pioneer group for the development of coordination in agricultural research.

Again and again in the years to come this same Association was to listen to two generations of college and station administrators extol the advantages of coordination. For several years a standing committee of the Association under the able leadership of Dean F. B. Mumford of Missouri has striven valiently to develop a "coordination consciousness" among agricultural research workers and has sponsored the activities of special committees created to coordinate research in specific fields.

Throughout his long and useful service in the Office of Experiment Stations, Dr. E. W. Allen was an ardent disciple of coordination and cooperation. Year after year in the annual reports of that Office, Dr. Allen emphasized and reemphasized the benefits of collective effort in research. Optimistically he recorded the increasing number of projects cooperative between the individual bureaus of the Department of Agriculture and state stations and the less impressive number of cooperative projects involving only the latter.

.Nor has interest in this subject been limited to the administrators of our research institutions. Practically every one of the professional societies in which agricultural research workers are affiliated has given more or less attention to the possibilities of coordinating work in its own field. Serious attempts have been made to develop effective working arrangements for cooperative attacks within a field or on specific problems. One organization now actively engaged in trying to develop machinery for such coordination is the American Association of Agricultural Engineers.

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[1] Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio.

[2] Agronomist.

With such a background, one may reasonably ask why, at this late date, should our own Society consider it advisable to reopen the question of coordination in the field of agronomy? The fact that we are doing so implies either that such coordination does not now exist or that there is still opportunity for realizing more of the benefits claimed for it. I assume that the purpose of this discussion is to take stock of the present situation, to examine it critically with an eye for the causes of past failures in coordination, and to develop ideas that may serve as a basis for future action. Perhaps there is reason to hope that this discussion may be productive of more definite results than previous efforts. Anyone who has participated in the activities of a society such as ours, and particularly in the work of its various committees, can scarcely help having been impressed with the tendency for us to pump ourselves full of enthusiasm when we get together at the annual meeting and for this same enthusiasm to evaporate at a rate about proportional to the square of the time after its adjournment. We go back to our respective jobs, put our plans and good intentions in cold storage, and like as not leave them there until we get a letter from the Secretary asking whether our committee will have a report to present at the annual meeting—next month. It is not always as bad as this, but I believe you will agree that such is the tendency.

But there may be reason for hope that the present discussion may lead to less ephemeral results. At least, we have the stimulus of adversity. We are being asked to justify our present organizations and methods. The fact that drastic cuts have been made in appropriations for agricultural research, often out of proportion to reductions in other branches, suggests that our constituency is beginning to question whether the benefits of research as now organized have justified its cost. Moreover, research workers are probably not entirely immune to the psychology of change which now pervades our entire national life. Perhaps research institutions need to emulate industry in its present movement away from individualism and toward a system involving collective action and the elimination of wasteful competition.

In what follows we shall be thinking of coordination in its broader sense, involving not only correlation—which we understand as the planning of investigations in a manner to make the results comparable because they are of the same kind and measurable in the same terms—but more than that we shall prefer to include under the term coordination joint planning and joint attack involving, wherever feasible, a division of labor among the coordinators.

We are now ready to inquire into the present status of coordination in soils research in the United States. In the 1932 report of the Joint Committee on Projects and Correlation of Research of the Association of Land Grant Colleges and Universities we find the statement that there were active during that year 71 cooperative research agreements between the federal Bureau of Chemistry and Soils and the state stations. Of this number 48 were concerned with lines of investigation that were being carried on simultaneously in four or more states. This group included cooperation on soil surveys in 24 states, on concentrated fertilizer investigations in 10 states, on soil erosion investigations in 9 states, and on fertilizer investigations with potatoes on prominent soil types in 5 states. Compared with the total number of 71 cooperative agreements between the Bureau of Chemistry and Soils and state stations in 1932, we find listed in the annual reports of the Office of Experiment Stations 96 such agreements in 1931, 88 in 1930, and 115 in 1929. So far as this type of cooperative research is concerned, if we base our opinion merely on numbers of agreements, there has been a significant decrease during the past 4 years. There exist no doubt some cooperative arrangements involving only the state stations, but no attempt has been made to ascertain the number of these.

One example of fairly satisfactory coordinated effort has been the program of cooperative investigation on methods of fertilizer application sponsored by the Joint Committee on Fertilizer Application which has involved to date some 30 to 35 state stations, the federal bureaus of Agricultural Engineering and Chemistry and Soils, and the National Fertilizer Association. Some investigations of a semi-demonstrational type have been conducted concurrently in several states under the sponsorship of commercial agencies, such as the National Fertilizer Association, as for example the pasture fertilization studies made during recent years in the northeastern states. However, of the total of approximately 500 experiment station projects dealing with soils and fertilizers as reported to the Office of Experiment Stations I believe that we are safe in estimating that not over 15%, or less than one in six, involve either cooperation between state stations or between the latter and the federal government.

Outside of soil survey, soil erosion, and a few fertilizer studies, mostly of a field nature, projects involving coordination in soils research are, so far as I am aware, practically nil. In most of the more technical or fundamental fields, little if any coordination has been attempted.

From the progress so far made toward regional coordination in soils research I believe that it is logical to conclude either (1) that only a small fraction of the soils problems under investigation are of such a nature as to benefit from coordination, or (2) that the nature of our research institutions is such as to mitigate against coordination, or (3) that soils investigators as a class are individualistic and non-cooperative, or (4) that we have been asleep to the possibilities of coordination and hence unappreciative of our responsibilities to the public we serve.

Let us examine the first of these conjectures. In what types of soils studies are benefits to be expected from coordination? We are accustomed to thinking of soils research as falling into two categories, i.e., fundamental and applied. Admittedly there is no sharp demarcation since there are many problems with both fundamental and applied aspects.

In general we consider as fundamental, researches whose results are of universal application. In such studies the influences of local environment are at a minimum. For example, principles evolved through studies of base exchange in California, we expect to hold true in Wisconsin or New Jersey (some times they do not, of course, but then we question the validity of the principles). In this field, duplication, beyond the minimum required to check the original findings, is wasteful. It is wasteful because the effort so expended could be applied with greater profit to the study of unexplored problems. Thinking of coordination as applied to this type of research, we should expect it to take the form of collective planning among workers in a particular field with some effort to allocate different phases of the problem to different workers, thereby eliminating duplication and increasing the common efficiency. The need for such coordination hinges upon the existence of wasteful duplication. Does it exist?

The answer is not hard to find. Ask almost any experienced worker in this field whether or not he has had the experience of being about ready to publish on some problem only to have some other worker beat him to print with the results of a similar study. In fact, the tendency for soils research to go in waves is well recognized. Some one publishes a piece of particularly stimulating original research on some hitherto neglected problem. Immediately several additional problems arise in the minds of other workers in the same general field. Immediately and with rare independence each worker starts working on as many of these problems as his time and facilities permit. Thus a wave is started. The style is set. When it is style to work on hydrogen-ion concentration, everybody works on hydrogen-ion concentration. When the style shifts to base exchange, everybody shifts to base exchange, and so on. Naturally, such a system leads to considerable duplication and to the more or less simultaneous discovery of the same facts by several workers.

Since it is a well-recognized principle that the first man to print gets the credit, the tendency is to rush to print without wasting time on verification. Only a few days ago one of the men in my own laboratory came to me and suggested that we had better get into print with the results of a problem we have had under study during the last 3 years, the fact that additional study of some aspects of the problem were highly desirable notwithstanding. He had discovered that at least two other laboratories were working on the same problem. While admitting that bringing to bear different points of view in the attack on a problem is desirable, one might reasonably raise the question whether these different points of view might not be more effectively brought to bear in planning the attack. One natural result of such a hit and miss system is for the more general or more obvious phases of a problem to be solved repeatedly with less obvious but perhaps equally important phases receiving little or no attention, and in any case considerable delay in working out a well-rounded solution.

To illustrate by only one random example, a fundamental problem with definite practical applications, that of determining and evaluating the factors affecting the rate at which limestone dissolves in acid soils, practical in that the information is essential to the accurate evaluation of commercial ground limestones. The problem is, of course, to be able to advise the farmer what relative efficiencies to expect from two or more commercial ground limestones at any given time or during any given period after application. This is a problem that has concerned almost every station in the lime-using area of the United States. Almost every station has done some work on it. A cursory examination of the published reports reveals that the problem has been attacked in much the same empirical fashion at the different stations, with, however, sufficient variation in procedure as to preclude any very satisfactory correlation of the results as a whole. Usually, separates representing different ranges of particle size or composites of different size distribution have been incorporated in acid soils and their effects measured at some later period, frequently indirectly through the yield of plants in the greenhouse or field, but in some cases chemically by measuring the change in soil acidity or the loss in carbonates. Usually, limestone of only one chemical composition has been used, sometimes two. There has been a decided lack of uniformity in the screen sizes employed in preparing the separates and much variation in the size range included in a single separate. Commonly, only one kind of soil and one rate of application have been employed. In most cases only the results at the end of a single time period have been measured and the units of measurement have been quite diverse. On the whole, very little real progress has been made toward the solution of the fundamental problem. Everybody knows something about it and no one very much. Let us imagine now that in the early stages of the investigation of this problem workers in the several states had come together, and after a careful analyses of the factors likely to be involved, had decided upon a coordinated attack with one state responsible for one phase, another for some other phase, but with sufficient duplication all the way round to check each others findings. A uniform system of screen sizes is selected, also a uniform method of measuring the rate of dissolution, probably through loss of carbonates, since it is the only direct one. The preliminary analysis of the problem would have revealed that the rate of dissolution, and hence the efficiency of different limestones, is likely to be influenced to an important degree by the following factors: (1) The surface exposed as determined by mean particle size and shape, changing of course progressively as dissolution proceeds. (2) The rate of dissolution per unit surface exposed, depending on (a) the mineralogical character of the stone, particularly the proportions of dolomite, calcite, and silicate impurities; (b) the reaction of the soil, changing of course as dissolution proceeds; (c) the rate of application in relation to the amount of limestone required to reach equilibrium; (d) the relative rates of diffusion and percolation, dependent of course on the physical characteristics of the soil and in field soils upon the weather; and (e) the partial pressure of CO_2 in the soil atmosphere reflecting respiratory activity of soil micro-organisms.

If then, instead of an uncorrelated empirical attack, it had been agreed in the beginning that certain stations would attack only certain of the foregoing phases, other stations other phases, and if, from time to time the workers had come together and integrated their findings, I am confident that we should today be much closer to the solution of the problem as a whole.

I have thought it worthwhile to present this example in some detail since it is a rather typical one and brings out both the present lack of coordination and its effects and suggests one way in which coordination might profitably be applied to fundamental researches.

Let us now turn to the question of possible benefits from coordination in the field of applied soils research. By the latter I am thinking of problems which for the most part are concerned with plant response, are ordinarily attacked in the field, and are influenced notably by environmental factors. In scope of interest such problems vary widely. Some are national in scope, some regional, some concern only one state and some only one location within a state. In our discussion we are thinking mostly of coordination on a regional or national basis, but the principles apply equally within a single state with the difference, however, that our organization for research by states makes the question of method of coordination within the state a relatively simple one. The primary objective in this type of investigation is the obtaining of information that can be directly employed in advising farmers and the case for coordination will stand or fall depending upon whether or not it does or does not contribute to the attainment of this objective.

Of first importance in the imterpretation and application of field experiments are the influences of environment. Perhaps the chief criticism that can be made of much work in the past, and one that still applies too generally, is that the results have been over-applied. Every time we grow a crop the final result expresses the response of that plant to a complex and interrelated group of climatic, soil, and genetic factors. The effect of any specific soil factor that we may choose to study in a field experiment can only be interpreted in terms of its relation to all other factors. As the latter vary, so does the effect of the former, often notably as most field investigators are aware. In general, little attempt has been made as yet to measure and evaluate the influence of other factors than those under study, or to classify the areas within even the boundaries of a single state on the basis of similarity of environmental factors. With the exception of soil type, whose significance as a determinant of crop response has come in recent years to be fairly well understood, other factors are given little or only general consideration in translating the results of a field experiment to other areas, areas that are often quite different ecologically. Were it known, it is not unlikely that the cost to farmers of errors in the application of the results of field experiments would be found to exceed greatly the actual cost of making these experiments.

To correct this situation, and correct it we must, I believe, if field experimentation is to make real progress in contributing to the improvement of our agriculture, will require more than mere refinebranches of agricultural science, and between all stations in the agreement all important branches will be covered, but each station will no longer attempt to deal with all subjects. Thus four stations in four adjacent states might agree that A would make a big thing of soils and crops production, B of animal nutrition, C of plant diseases and pests, and D of dairy husbandry (other subjects being similarly allocated). B, C, and D would then give up soil research as a major activity, though they would of course have a local advisory soil staff which would still continue to make local field trials. A, however, would undertake to help them all with advice, the training of acceptable post graduates, and such other services as a research staff renders to an institution.

"The advantage of this method is that instead of having four soil research institutes all cramped for want of funds and spaces, there is only one, but it has considerably more funds and therefore can ensure retention of the best men and provision of the best equipment.

"This is the method we adopt in England and we find it works satisfactorily. At Rothamsted, for example, we confine ourselves to crop production, including soils and plant pathology. We do not, however, concern ourselves with dairy husbandry, which is done at Reading; or animal genetics, done at Edenburg; or animal nutrition, done at Cambridge and Aberdeen; or plant genetics done at Cambridge and Aberystwyth. We are in close touch with all these places and have machinery for dealing with border line problems: indeed our relations are at least as friendly as if they were placed on our own campus, and cooperation is no more difficult. Within each institution we find many advantages in having this closely knit compact organization as it enables us to tackle big problems with the certainty that the work will be continued year after year."

In America, outside the U. S. Dept. of Agriculture, we are organized on the basis designated as "regional" by Sir John Russell. Most of us probably would not agree that centering all research in a given line in a single institution in a country as large as ours is advisable. I doubt also how far one could get with a suggestion that several states within a given region cooperate on the English basis. I am afraid that we must accept our organization pretty much as it stands and make the best of it. But as Russell says of this system, "The chief objection to it is its costliness: it breaks down directly money is short." I think we can agree that money has been that way. However, is there any real reason why decreased funds cannot be offset in part by increased efficiency gained through coordination between our present institutions? I cannot subscribe to any idea that soil research men would be irresponsive to such a plan providing it recognized certain fundamental principles which I shall mention shortly. There may be a few men, who, possessed of a superiority complex combined with the desire for glory, jealously guard every new idea they get until they have developed it to the point where it can be thrust before an astonished world. But I believe that the vast majority of soils workers in this country would welcome a plan for closer contacts, mutual planning, and even allocation of problems under a democratic arrangement.

I just indicated that certain conditions are probably essential to the success of any plan for coordinating soils research. First of all, participation in the plan should be voluntary on the part of the worker or the institution. Coordination implies cooperation, and cooperation is almost the antithesis of coercion.

Control of policies and program should rest in the hands of the research men working together on a given problem or within a given field, in other words, there should be democratic control in full measure. Research workers cannot be expected to take kindly to any scheme that savors of regimentation or centralized control. Their program must be of their own making, not one handed down to them.

Next, and I believe this is the most essential condition for success, the plan must provide for a close working contact between men in a given field, one that will facilitate the exchange of ideas and resources. Obviously, the workers in a given problem cannot work together at a single institution, as at Rothamsted. But, might not much the same benefit come from occasional opportunities for those working on a given problem to get together for informal conferences where they could sit down together and talk over developments, exchange experiences, and plan new ways of attacking problems? Soils research as a whole would need to be sufficiently subdivided that the individual coordinating groups would not be too large or lack intensity of interest; otherwise they might be expected to take on some of the less desirable attributes of scientific societies. By all means they should be made up of workers—not administrators.

Lastly, those in charge of administering our research institutions would need to be sold to the plan. Failure of one or two leaders in a given field to participate in the activities of their particular group because no funds were allowed them for out of state travel would be a serious impediment to success. Administrators would need to be educated to the fact that money spent for travel to these research conferences might easily return to the state many times as much as a like amount spent for salaries or facilities. Since the depression settled down upon us it has been practically impossible at many institutions for a worker to obtain funds for travel beyond the borders of his own state. While this policy may be justified as a temporary expedient, in lieu of firing the worker, its continuance would certainly doom to failure any effort to increase our combined efficiency through coordination. Personally, I have little doubt but that administrative support could be obtained for any well-thought-out plan for coordinating research in agronomy or any other field.

Of what, we may ask, would such a plan consist? Specifically, how might we organize to bring about coordination of the right kind in the proper degree? Here it becomes necessary to draw upon one's imagination. This I propose to do, even disregarding certain obvious difficulties that might arise because of inflexibility in our present research organizations.

I would propose as the fundamental working units in the plan, permanent research commissions made up of the active workers in each of the major fields of soils investigation, including both state and federal workers. Just how much should be included within the province of a single commission is a matter for conjecture. My thought is that the entire field would need to be subdivided further than has been done in setting up the various commissions of the International Society of Soil Science. While I have made no attempt to work out a subdivision, the type of unit I have in mind is indicated by suggesting that there might be commissions dealing with such fields as soil erosion, soil tillage, physico-chemical and colloid problems, fertilizers and fertilizer application, studies of plant nutrition and diagnostic methods, soil morphology and genesis, pasture soil problems, and so on. In any case, the particular subdivision decided upon should be subject to change should it become apparent that its scope was either too broad or too narrow.

To make possible group action leading to coordination, provision should be made for group conferences at such intervals as the group might decide as most desirable. These meetings should be real working conferences with a minimum of formality. They would be devoted to such activities as:

1. The analysis of problems within the field, determining the status of knowledge applying to each and deciding where additional study could most profitably be made.
2. Reviewing the research accomplishments of individual members and exchanging experiences, ideas, and observations. Every investigator makes many random observations that are never followed up and never get into print. The integration of such random observations might easily point the way to the solution of important problems.
3. Planning for joint attack on certain problems. This might involve the allocation of certain phases to individual workers depending upon their interests, their facilities, and their willingness to cooperate. In other cases, it might involve the planning of multiple experiments and the working out of methods for evaluating environmental factors.
4. The setting up of certain standards of procedure or usage within the field.
5. Arranging for the interchange of materials or equipment, etc.

Some of the activities mentioned would be carried on by the group as a whole. In some, only those members of the group interested in specific problems would work together. The time devoted to such a conference should be whatever was necessary to accomplish its purpose. It might be one day or a week. The meetings could probably be rotated among the various research institutions, thereby giving the workers an opportunity to gain first-hand informotion regarding the methods and facilities of others in the same group.

These commissions would have as their important officers a chairman, elected annually, and a permanent executive secretary or group coordinator. The former would perform the usual functions attending such an office, presiding at meetings, appointing committees, etc. The latter officer would function quite differently than the usual secretary of a committee. My thought is that the executive secretary would be a man of experience and recognized standing in the particular field and chosen by the group on the basis both of his knowledge of the field and of his administrative ability. He would devote all or a major portion of his time to the duties of his position. Naturally some one would have to pay him for his services, and here is where it may be necessary to stretch our imaginations a trifle. To me it seems quite logical that this man should be attached to the U. S. Dept. of Agriculture, either in the Bureau of Chemistry and Soils or in the Office of Experiment Stations. As I shall explain shortly, the chief function of this man would be to act in the capacity of a coordinator and service agent for the particular research group of which he was a member. I have always believed that the research bureaus of the Department of Agriculture should have these two primary functions, *viz.*, (1) the prosecution of research on problems of national scope that legitimately cannot be attacked by the individual state stations or that require facilities not possessed by them, and (2) the coordination of the research of the country as a whole in their respective fields. I shall not venture to suggest to what extent these unctions are now being fulfilled but shall proceed to a consideration of the functions of the executive secretary of a research commission.

Primarily he would serve as the clearing house for information within the field. He would take the lead in analyzing the field of research, would keep continually in touch with new developments throughout the world, fitting them into the picture for the benefit of workers within the field. In some cases he might serve as a traveling contact man for the group, acting as the medium for the exchange of ideas that might aid in better coordinating the work on certain problems. He would make arrangements for the group meetings, serve as secretary, and see that plans and proceedings were mimeographed or printed and properly edited. He would serve as intermediary for the exchange of materials or equipment among workers. He would call the attention of workers on particular problems to articles in foreign journals where these were not generally available. He might in some cases arrange for the provision of a centralized agency for statistical service or for the translation of articles in the less familiar foreign languages. He would establish contacts with other groups and arrange for joint meetings on problems of a borderline character. Throughout, his functions would be primarily service to the group and not of a directional character. Together with the group chairman he would represent the commission on the Soils Research Council.

You ask, what is the Soils Research Council? This is the superorganization in the plan. I would conceive it as made up of the chairmen and executive secretaries of the individual commissions. At its annual meetings, probably held in connection with the meetings of the American Society of Agronomy, it would make provision for coordinating the work of the various commissions, would arrange for inter-group meetings to consider borderline problems and for meetings of one or more groups with workers in other fields of agriculture where there was an overlapping of interest on any problem. It would set up new commissions as the need for these became apparent, discontinue or combine others when needed, determine upon general matters of policy and establish standards of ethics in coordination, advise on inter-institutional relationships, and supervise the development of coordinated programs involving several groups, such as soil studies in relation to land utilization.

This completes the plan as I have conceived it. Admittedly it is visionary and Utopian. I can see a good many obstacles to its practical accomplishment. It has been presented with the hope that it might stimulate some one else to think up a better one. I have at least convinced myself that the introduction of coordination in larger measure than it now exists in the field of agronomic research is advisable and I firmly believe that the development of suitable means for doing so should not unduly tax the coordinated intelligence of this Society.

SILAGE PALATABILITY TESTS[1]

H. L. WESTOVER[2]

The Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, has for a number of years conducted experiments with silage materials and containers. Silage palatability tests carried on at a number of field stations have brought out interesting results and are reported on in this paper.

In a study to determine the feasibility of utilizing weeds and other plants, both green and dry, that might otherwise be wasted, all such materials available, as well as plants generally utilized for the purpose, were ensiled experimentally. For this purpose discarded oil, vinegar, or similar barrels were used, the heads being removed and then replaced after filling, as described by Westover and Garver.[3] Where dry materials were ensiled sufficient water was added to bring the moisture content to approximately 60%. These investigations, covering a period of 3 or 4 years, were carried on at the following experiment stations: Arlington Farm, Rosslyn, Va.; Redfield Field Station, Redfield, S. Dak.; Northern Montana Branch Station, Havre, Mont.; Judith Basin Branch Station, Moccasin, Mont.; Fort Hays Branch Station, Hays, Kan.; Oregon Agricultural Experiment Station, Corvallis, Ore.; U. S. Yuma Field Station, Bard, Calif.; and the Coastal Plains Station, McNeill, Miss.

Where sufficient material was readily available, the barrels were filled entirely with one kind of silage. In many cases, however, two or more kinds separated by newspaper were placed in the same barrel. This plan worked very satisfactorily except with very succulent materials or with those with strong odors which often imparted their characteristics to other silages in the barrel. The barrels were generally allowed to stand three months or more before opening by which time the silage had undergone practically as much change as takes place in a year or more with the exception of changes that result in spoilage which are generally attributable to the presence of too much or too little moisture in the material.

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[1] Contribution from Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Received for Publication, February 4, 1933.

[2] Senior Agronomist. The author acknowledges the cooperation of Samuel Garver, N. F. Woodward, H. A. Schoth, R. E. Getty, and H. R. Reed, of the Division of Forage Crops and Diseases, and T. E. Woodward, of the Bureau of Dairy Industry, in carrying out these tests.

[3] WESTOVER, H. L., and GARVER, S. L. A cheap and convenient experimental silo. Jour. Amer. Soc. Agron., 12. 1920.

The palatability of the silages was determined by feeding dairy cows or beef cattle, using good corn silage as the standard. The silages put up at Arlington Farm were fed to dairy cattle at the Dairy Experiment Farm, Beltsville, Md. The silages put up at Redfield, S. Dak., were fed at that station each year to three head of young beef cattle that received in addition alfalfa and corn. During the 2 or 3 months feeding period the cattle gained steadily and at the close of the test were in excellent condition. In most other cases dairy cows were used in determining the palatability of the various silages. As was to be expected, cattle that had never tasted silage before sometimes ate even the best corn silage rather reluctantly at first, but after a few days consumed the various silages as readily as cattle that had been accustomed to this feed. Considerable difference was noted in individual animals as regards the relish for silage and the amount consumed. Based on observations made on palatability, the various silages have been placed in the following groups:

1. *Eaten with avidity.*—This group includes those silages that were eaten as readily as the best corn silage.
2. *Eaten readily.*—Silages in this group were eaten entirely in a short time, though cattle showed a preference for the silages in group one.
3. *Eaten reluctantly.*—Silages in this group were usually not eaten so long as any of those classified in groups 1 and 2 were available but were generally largely consumed between feedings.
4. *Eaten only partially.*—Less palatable than any of the preceding and from 25 to 75% wasted.
5. *Refused entirely.*

The results of these tests are presented in tabular form in Table 1. In addition to palatability, the stage at which the material was ensiled, the condition when opened, and the odor of the silage are given as having a bearing on palatability. All the silages tested at Redfield, S. Dak., as well as those put up at Arlington Farm, Va., and fed at Beltsville, Md., are given in the table. Similar materials tested at other places generally have not been repeated, those listed consisting mainly of plants seldom ensiled.

As shown in Table 1 silages made from the same plant often vary in palatability, depending largely upon the stage of maturity when the crop was ensiled. In a few cases silages that ordinarily would have been very palatable were affected adversely by sloppy and strong-smelling silages in the same barrel. The variation in the relative palatability of the silages at the different stations is probably due in part to the individual peculiarities of the animals and to tastes influenced to some extent by the kind of feed which they were accustomed to receiving. Cattle that were accustomed to silage usually ate the various kinds more readily than those that had never tasted

TABLE 1.—*Silage palatability tests.*

Silage	Stage of maturity	Condition when opened	Odor when opened	Relative palatability				
				Eaten with avidity	Eaten readily	Eaten reluctantly	Eaten partially	Refused
Redfield Field Station, Redfield, S. Dak.								
Alfalfa alone	Early bloom	Excellent	Pleasant	X				
Field peas	Bloom	Good	Rank		X			
Corn	Glazed	Excellent	Pleasant	X				
Oats	Milk	Excellent	Pleasant		X			
Russian thistle	Bloom	Poor	Putrefactive					X
Russian sunflowers	Bloom	Good	Good	X				
Alfalfa and vinegar	Early bloom	Excellent	Pleasant		X			
Wild sunflower	Bloom	Good	Resinous		X			
Sweet clover (*M. alba*)	Early bloom	Good	Characteristic		X			
Corn stover and water		Good	Pleasant			X		
Kale	Max. growth	Fair	Characteristic		X			
Rape	Max. growth	Fair	Characteristic		X			
Corn in layers	Glazed	Excellent	Pleasant	X				
Sweet sorghum in layers and uncovered	Grain in dough	Much spoilage	Moldy		X			
Alfalfa uncovered	Early bloom	Much spoilage	Unspoiled portions pleasant		X			
Alfalfa and molasses	Early bloom	Excellent	Pleasant	X				
Hemp	Early bloom	Good	Characteristic			X		
Sweet sorghum in layers	Late bloom	Excellent	Pleasant		X			
Russian sunflowers in layers	Late bloom	Good	Pleasant		X			
Smutty corn	Glazed	Good	Pleasant	X				
Russian thistle and sour milk	Bloom	Sloppy	Putrefactive					X
Alfalfa (loose pack)	Bloom	Excellent	Pleasant	X				
Sweet sorghum	Soft dough	Good	Pleasant		X			
Corn	Glazed	Good	Pleasant	X				
Kaoliang	Soft dough	Good	Pleasant		X			
Wild sunflower	Full bloom	Good	Resinous		X			
Wild sunflower and vinegar	Full bloom	Good	Resinous		X			

Golden rod	Full bloom	Good	Characteristic		X		
Golden rod and vinegar	Full bloom	Good	Characteristic		X		
Willow sprouts		Fair	Pleasant		X		
Sweet corn and alfalfa	Corn glazed	Excellent	Pleasant	X			
Sweet corn alone	Glazed	Excellent	Pleasant	X			
Soybeans	Seed fully developed	Excellent	Pleasant		X		
Soybeans and corn	Corn glazed	Excellent	Pleasant	X			
Sugar beet tops		Wet	Pleasant		X		
Sweet sorghum and alfalfa	Sorghum nearly mature	Excellent	Pleasant	X			
Russian thistle and pea vine straw	Bloom	Rather dry	Fair				X
Wild sunflowers and pea vine straw	Bloom	Rather dry	Fair			X	
Russian sunflowers and pea vine straw	Bud	Rather dry	Good			X	
Russian sunflowers wilted	Full bloom	Rather dry	Good			X	
Wild sunflowers alone	Full bloom	Good	Resinous		X		
Wild sunflowers and sour milk	Full bloom	Good	Resinous			X	
Wild sunflowers and mashed potatoes and yeast	Full bloom	Good	Resinous			X	
Wild sunflowers and yeast	Full bloom	Good	Resinous			X	
Wild sunflowers and yeast	Full bloom	Good	Resinous			X	
Wild sunflowers and water	Full bloom	Good	Resinous			X	
Wild sunflowers and mashed potatoes	Full bloom	Good	Resinous		X		
Russian sunflowers and mashed potatoes	Full bloom	Good	Resinous		X		
Wild sunflowers and mother of vinegar	Full bloom	Good	Resinous		X		
Wild sunflowers and yeast	Full bloom	Good	Resinous		X		
Wild sunflowers and molasses	Full bloom	Good	Resinous		X		
Russian sunflowers	Bloom	Good	Resinous		X		
Russian sunflowers and vinegar	Bloom	Good	Resinous		X		
Russian sunflowers and yeast	Bloom	Good	Resinous		X		
Russian sunflowers and molasses	Bloom	Good	Resinous		X		
Russian sunflowers and sour milk	Bloom	Good	Resinous		X		
Sudan grass	Full bloom	Good	Pleasant		X		
Russian thistle and straw	Full bloom	Dry	Fair			X	
Russian thistle and wild sunflower	Full bloom	Good	Fair			X	
Wild sunflowers and corn	Nearly mature	Good	Pleasant	X			
Russian sunflowers and corn	Nearly mature	Good	Pleasant	X			
Cleome sp.	Full bloom	Wet	Disagreeable			X	

TABLE 1.—*Continued.*

Silage	Stage of maturity	Condition when opened	Odor when opened	Relative palatability				
				Eaten with avidity	Eaten readily	Eaten reluctantly	Eaten partially	Refused
Cocklebur and molasses	Burs well formed	Wet	Fair			X		
Wild sage (*Artemesia* sp.) and molasses	In bud	Dry	Characteristic		X			
Cocklebur and water	Burs well formed	Good	Fair			X		
Sage (*Artemesia* sp.) and mother of vinegar	In bud	Dry	Characteristic			X		
Cocklebur	Burs well formed	Good	Fair			X		
Corn and sage (*Artemesia* sp.)		Good	Sage		X			
Gum weed (*Grindelia* sp.) and yeast	Full bloom	Dry	Characteristic					X
Gum weed (*Grindelia* sp.) and mother of vinegar	Full bloom	Dry	Characteristic					X
Gum weed (*Grindelia* sp.) and vinegar	Full bloom	Dry	Characteristic					X
Soybeans	Full bloom	Good	Pleasant		X			
Russian sunflowers	Mature	Good	Resinous			X		
Wild sunflowers and molasses	Mature	Good	Resinous			X		
Artichoke tops (*Helianthus tuberosus*)		Good	Resinous			X		
Tomato tops	Wilted	Slimy	Rank					X
Squash vines	Wilted	Slimy	Rank					X
Cosmos	Bloom	Good	Characteristic			X		
Cosmos and vinegar	Bloom	Good	Characteristic			X		
Russian thistles and sour milk	Bloom	Good	Fair				X	
Marsh elder (*Iva zanthifolia*) and sour milk	Full bloom	Dry	Fair				X	
Marsh elder (*Iva zanthifolia*) and sour milk	Full bloom	Dry	Fair				X	
Russian sunflowers	Mature	Wet and woody	Resinous				X	
Alfalfa straw and vinegar		Dry	Acrid				X	
Alfalfa straw and water		Dry	Acrid				X	

Alfalfa straw and molasses		Dry	Acrid				X
Alfalfa straw and Russian thistle		Dry	Pleasant				X
Brome grass (*Bromus inermis*)	Hay stage	Good	Pleasant		X		
Alfalfa	⅓ bloom	Good	Pleasant		X		
Nettle (*Urtica gracilis*)	⅓ bloom	Fair	Rank			X	
Sweet clover (*Melilotus alba*)	Bud	Fair	Pleasant		X		
Alfalfa and molasses	In bloom	Good	Pleasant	X			
Mustard (*Brassica nigra*)	Full bloom	Slimy	Characteristic				X
Alfalfa alone	⅓ bloom	Good	Pleasant	X			
Rye	Soft dough	Wet	Pleasant		X		
Sour dock (*Rumex acetosa*)	Seeding	Fair	Pleasant		X		
Milkweed (*Asclepias syriaca*)	Full bloom	Wet	Pleasant		X		
Lamb's quarter (*Chenopodium album*)	Past full bloom	Good	Pleasant		X		
Red root (*Amaranthus retroflexus*)	Past full bloom	Good	Pleasant	X			
Mixed weeds	Past full bloom	Good	Pleasant		X		
Sweet clover (*Melilotus alba*)	Full bloom	Good	Characteristic		X		
Pigeon grass (*Chaetochloa viridis*)	Full bloom	Wet	Rank from potatoes		X		
Potato tops	Past full bloom	Sloppy	Rank				X
Barnyard millet	Full bloom	Wet	Rank from potatoes		X		
Barley	Soft dough	Wet	Rank from potatoes		X		
Field peas	Maturing	Good	Unpleasant			X	
Bachelor's button (*Centaurea* sp.)	Full bloom	Good	Unpleasant		X		
Wheat	Soft dough	Good	Unpleasant from peas		X		
Field peas	Full pod	Good	Unpleasant			X	
Oats	Milk	Good	Unpleasant from peas		X		
Giant ragweed (*Ambrosia trifida*)	Early bloom	Wet	Rank odor of kale			X	
Rape	Max. growth	Good	Rank			X	
Annual chrysanthemum	Full bloom	Good	Characteristic			X	
Kale	Max. growth	Good	Characteristic			X	
Russian thistle	Nearly mature	Good	Pleasant				X
One-half Russian thistle, ½ alfalfa	Nearly mature R. thistle; ⅓ bloom alfalfa	Good	Pleasant		X		

TABLE 1.—*Continued.*

Silage	Stage of maturity	Condition when opened	Odor when opened	Relative palatability				
				Eaten with avidity	Eaten readily	Eaten reluctantly	Eaten partially	Refused
One-half Russian thistle, ½ partly cured alfalfa	Nearly mature R. thistle; ⅓ bloom alfalfa	Good	Pleasant		X			
Russian thistle, partly cured	Nearly mature R. thistle; ⅓ bloom alfalfa	Dry and moldy	Mold		Not fed			
Marsh elder (*Iva xanthifolia*)	Early bloom	Good	Characteristic			X		
Gum weed (*Grindelia* sp.)	Early bloom	Dry	Resinous				X	
Ragweed (*Ambrosia trifida*)	Early bloom	Good	Characteristic			X		
Gum weed (*Grindelia* sp.) and molasses	Early bloom	Dry	Resinous				X	
Ragweed (*Ambrosia trifida*) and molasses	Early bloom	Good	Characteristic			X		
Ragweed (*Ambrosia trifida*) and yeast	Early bloom	Dry	Characteristic			X		
Wild sage (*Artemesia* sp.) and yeast	Bud	Dry	Characteristic					X
Wild sunflowers and yeast	Early bloom	Good	Resinous				X	
Russian sunflowers and yeast	Bud	Good	Resinous				X	
Wild sage (*Artemesia* sp.)	Bud	Dry	Characteristic		X			
Wild sunflowers	Early bloom	Good	Pleasant		X			
Prickly lettuce (*Lactuca* sp.)	Early bloom	Good	Pleasant		X			
California poppy (*Eschscholtzia californica*)	Full bloom	Wet and slimy	Pleasant		X			
Russian sunflowers	Bud	Wet and slimy	Pleasant		X			
Hemp	Bud	Dry and woody	Pleasant			X		
Millet	Dough	Good	Pleasant	X				
Nasturtiums	Full bloom	Wet	Characteristic			X		
Oats and field peas	Nearly mature	Fair	Pleasant		X			
Arlington Experiment Farm, Rosslyn, Va.*								
Buckwheat	Dough	Good	Putrefactive		X			
Corn	Milk	Good	Pleasant	X				
Russian sunflowers	Milk	Good	Resinous			X		
Hemp	Bloom	Dry	Characteristic				X	

Kudzu	Bloom	Good	Moldy		X			
Sudan grass	Dough	Good	Pleasant			X		
Soybeans	Podded	Good	Pleasant	X				
Corn and cowpeas	Full pod	Good	Pleasant	X				
Russian sunflowers and cowpeas	Nearly mature	Good	Resinous		X			
Cowpeas	Nearly mature	Good	Pleasant	X				
Russian sunflowers and soybeans	Nearly mature	Good	Resinous		X			
Corn and soybeans	Nearly mature	Good	Pleasant	X				
Jimson weed (*Datura* sp.)	Nearly mature	Slimy	Rank					X
Tomato tops	Nearly mature		Rank					X
Buckwheat	Nearly mature		Putrefactive		X			
Red root (*Amaranthus retroflexus*)	Nearly mature		Pleasant		X			
Orange sorgo	Dough	Good	Pleasant		X			
Soybean straw		Good	Pleasant			X		
Alfalfa	Early bud	Good	Pleasant	X				
Pearl millet	Seed mature	Dry	Pleasant			X		
Jack bean	Green pod	Good	Pleasant			X		
Velvet bean	Seed fully developed	Good	Pleasant		X			
Bonavist bean	Green pod	Good	Pleasant	X				
Prickly lettuce	Seed mature	Good	Pleasant			X		
Onion tops		Good	Characteristic			X		
Roselle (*Hibiscus sabdariffa*)	Bud	Good	Characteristic		X			
Adsuki beans (*Phaseolus angularis*)	Maturing	Good	Pleasant	X				
Castor beans	Bloom	Good	Pleasant			X		
Poke berry (*Phytolocca decandra*)	Nearly mature	Wet	Characteristic				X	
Rice bean (*Phaseolus calcaratus*)	Seed mature	Good	Pleasant		X			
Sweet potato tops		Good	Pleasant				X	
Alfalfa and molasses	Early bloom	Good	Pleasant	X				
Pennisetum sp.	Not mature	Good	Pleasant		X			
Sudan grass, 2d growth	Frozen	Good	Pleasant			X		
Jack beans (*Canavalia ensiformis*)	Frozen	Good	Fair			X		
Sweet sorghum	Frozen	Good	Pleasant	X				
Cowpeas	Frozen	Good	Pleasant	X				
U. S. Yuma Field Station, Bard, Calif.								
Cotton	Green boll	Good	Not disagreeable			X		
Okra	Green pod	Slimy and wet	Putrefactive			X		

*Palatability tests conducted in cooperation with Bureau of Dairy Industry, Beltsville, Md.

TABLE I.—*Concluded.*

Silage	Stage of maturity	Condition when opened	Odor when opened	Relative palatability				
				Eaten with avidity	Eaten readily	Eaten reluctantly	Eaten partially	Refused
Laguna corn	Hard dough	Good	Pleasant		X			
Native saltbush		Good	Disagreeable					X
Lamb's quarter (*Chenopodium murale*)	Early bloom	Slimy and wet	Strongly putrefactive			X		
Melilotus indica		Good	Strong of cumarin		X			
Australia saltbush (*Atriplex semibaceata*)	Bloom	Dry	Pleasant			X		
Alfalfa	Bloom	Good	Very pleasant	X				
Alfalfa and molasses (1 to 35)	Bloom	Good	Very pleasant	X				
Smart weed (*Polygonum hydropiper*)	Bloom	Dry	Pleasant					X
Russian sunflower	In bloom	Wet	Pleasant-resinous			X		
Wild hemp (*Sesbania* sp)	Just blooming	Slimy and wet	Slightly putrefactive			X		
Sweet, grain, and grass sorghums alone and in mixture, 26 lots tested	Soft to hard dough	Good	Generally pleasant	2	17	7		
Coastal Plain Experiment Station, McNeill, Miss.								
Crotalaria incana	Pods maturing	Slimy	Rank			X		
Sesbania macrocarpa	Green pods	Slimy	Putrefactive		X			
Lespedeza	Bloom	Good	Pleasant	X				
Guar (*Cyamposis tetragonoloba*)	Green pod	Slimy	Rank				X	
Cenchrus barbatus	Nearly mature	Slimy	Pleasant		X			
Florida beggarweed	Bud	Good	Pleasant		X			
Molasses grass (*Melinis minutiflora*)	Bud	Good	Pleasant			X		
Pigeon pea (*Cajanus indicus*)	Bud	Good	Pleasant		X			
Jack beans (*Canavalia ensiformis*)	Bud	Slimy	Putrefactive			X		
Corn and velvet beans	Corn dented	Good	Very pleasant	X				
Sugar cane	Green	Good	Pleasant		X			
Coffee weed (*Sesbania floridanum*)	Maturing	Slimy	Rank			X		

Peanut vines	Bud	Good	Pleasant		X			
Mexican clover (*Richardia scabra*)	Bloom	Good	Fair			X		
Cypress weed (*Eupatorium capillifolium*)		Good	Fair				X	
Napier grass	Max. growth	Good	Pleasant		X			
Kudzu		Good	Musty					X
Japanese sugar cane		Good	Pleasant		X			
State Agricultural Experiment Station, Corvallis, Ore.								
Wild gourd (*Micrampelis oregana*)	Early pods, ¾ ripe	Good	Agreeable			X		
Dog fennel (*Anthemis cotula*)	Full bloom	Good	Strongly characteristic			X		
Tangier peas	Fully podded	Excellent	Pleasant	X				
Canada thistle	Full bloom	Good	Pleasant		X			
Tarweed (*Madia* sp.)	Full bloom	Good	Strongly characteristic			X		
St. John's wort (*Hypericum* sp.)	Past full bloom	Very dry	Characteristic			X		
Braken (*Pteridium aquilinum pubescens*)	Full grown	Very dry	Agreeable				X	
Mustard	Past bull bloom	Good	Strong acid		X			
Horse beans		Good	Pleasant	X				
Jerusalem artichoke tops		Good	Pleasant	X				
Wild parsnip		Good	Characteristic				X	
Eureka clover (*Polygonum sachalinense*)		Good	Pleasant		X			
Russian sunflowers	Bud	Good	Characteristic			X		
Russian sunflowers	Full bloom	Good	Characteristic		X			
Russian sunflowers	Past full bloom	Good	Characteristic		X			
Russian sunflowers	Mature	Good	Characteristic		X			
Russian sunflowers, +4 oz. salt to 100 lbs.	Nearly mature	Good	Characteristic	X				
Russian sunflowers, +8 oz. salt to 100 lbs.	Nearly mature	Good	Characteristic	X				
Russian sunflowers, +mill-run feed 1 to 4	Nearly mature	Good	Characteristic	X				

it. This explains to a large extent why similar silages are not always placed in the same group in these different tests.

Usually, silages made from alfalfa and corn alone or from either of these mixed with other crops or materials were in excellent condition when the containers were opened and were eaten with the greatest relish. Russian sunflowers to which some salt had been added at the time of ensiling appeared to be about as palatable as corn silage. Without the salt, however, sunflower silage was not eaten quite as readily as corn silage. Other materials, such as yeast, vinegar, and sour milk added as "starters" to hasten fermentation or molasses seemingly exerted comparatively little influence on palatability. Sorghum silage generally appeared to be slightly less palatable than corn silage. Silages made from wild sunflowers and certain other weeds with a rather strong characteristic odor, such as cockle bur, marsh elder, and ragweed, although eaten with considerable reluctance, were eventually cleaned up. Depending to a large extent upon the stage of growth when they were ensiled, the various lots of Russian thistle silage varied in palatability and were sometimes eaten reluctantly, sometimes eaten only partially, and sometimes entirely refused.

Other silages generally eaten partially included corn stalks, alfalfa straw, grain straw, and certain weeds with strong odors. Silages usually entirely refused even when well preserved included woody plants with strong, undesirable characteristic odor and taste, such as gum weed and wild sage, and silages, that were rather dry when opened such as resulted from using nearly mature wild barley. Sloppy, slimy silages having a strong putrefactive odor were also usually rejected. On the other hand, certain silages that had a rather disagreeable odor, such as generally resulted from using field peas, were often eaten quite readily. As was to be expected, the silages that were in good condition when the containers were opened and that had a pleasing odor generally proved most palatable.

A BIOMETRICAL ANALYSIS OF YIELD TRIALS WITH TIMOTHY VARIETIES USING ROD ROWS[1]

H. FAIRFIELD SMITH AND C. H. MYERS[2]

This paper reports yield trials with strains of timothy which were conducted at Cornell University from 1920 to 1927. Twelve strains were sown in broadcast plats; and 72 strains, of which only 12 are considered in this paper, were sown in rod rows in 1920; and 39 strains were sown in rod rows in 1923.

Broadcast plats were 16½ feet by 49½ feet with pathways 1 foot wide between all plats. They were seeded with 150 grams of seed per plat, equivalent to 17.6 pounds per acre, on September 8, 1920.

The rod rows were 17 feet long, 3 feet apart, and had pathways 3 feet wide between ends. They were seeded with 0.71 gram of seed per row, equivalent to 1.14 pounds per acre, originally estimated as 10.3 pounds per acre regarding each row as an area of 17 feet by 4 inches. Seeding was done on September 8 and 9, 1920, and on September 15, 1923.

Each plat was cut as soon as convenient after its period of full bloom. Rod-row crops were bundled and dried on wire trays in the drier to air-dry weight and weighed in that condition.

Broadcast plats were cut with a mowing machine and the herbage was immediately piled into crates which were weighed in the field within 5 minutes of cutting. A random sample of 10 to 13 pounds was taken in a burlap bag, dried at 165° to 180°F, and used to determine the air-dry weight of the yield from the whole plat.

All yields were converted to tons per acre and this unit has been used throughout the paper. For this purpose a rod row was regarded as a plat 17 feet by 3 feet.

COMPARISON OF ROD ROWS WITH BROADCAST PLATS

The broadcast plats, sown in 1920, were harvested in the 3 years 1921–23. Eleven varieties were sown in duplicate and a twelfth (No. 1777) was sown as a check in six plats. In the light of recent statistical theory, it may seem unfortunate that the varieties were sown in a systematic, as opposed to a random, order. In this connection it should be recalled that at the time these plats were laid out, the idea of complete randomization in agronomic experiments had not become established to the extent that it since has. However, the check plats indicated no noticeable fertility gradient, and therefore it may be deemed permissible to assume that the systematic arrangement does not influence the results and that an analysis of variance may be performed upon them. The 28 plats were arranged in two series, and all 11 varieties plus three check plats occurred once in each series. For the analysis of variance the two series containing 28 plats were divided horizontally into two blocks, each block containing 14 plats. It was therefore possible to take out sums of squares to indicate changes in fertility between the two series and between blocks. For the purpose of analysis the six check plats were regarded as three varieties with two plats each.

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[2] Assistant Plant Geneticist, Division of Plant Industry, C. S. I. R., Canberra City, F. C. T., Australia; and Professor of Plant Breeding, Cornell University, respectively.

The analysis is given in Table 1. The deduction from the check plats that the area contains no marked fertility gradient is corroborated in that the mean squares between blocks and between rows do not differ significantly from the mean square for error. At the same time it may be mentioned that relative to such differences as do exist it has so happened that the two plats of each variety occurred either on the highest and lowest yielding quarters of the area or on the two intermediate quarters. It is unlikely, therefore, that the systematic arrangement can influence the results to any marked extent.

TABLE 1.—*Analysis of variance for yields from broadcast plats, 1921–23.*

	Degrees of freedom	Sums of squares	Mean square	log$_e$	z	P
Between varieties....	13	3.5522	0.2732	1.005	.452	slightly >.01
Between years.......	2	42.8089	21.4044			very low
Interaction: varieties vs. years..........	26	3.1216	0.1201	.183	.040	about .5
Between blocks......	1	0.2475	0.2475	.906	.402	>.05
Between rows........	1	0.2059	0.2059	.722	.310	>.05
Remainder..........	40	4.4314	0.1108	.102	——	——
Total.............	83	54.3675				

Other deductions from Table 1 are as follows: Differences between varieties may be regarded as significant, differences between years are relatively very great, the relative yields of varieties do not change in successive harvest years, and the standard error of the experiment is $\sqrt{.1108}$. Since there is a total of six yields for each variety, the standard error of the mean yield of a variety is $\sqrt{\frac{.1108}{6}} = .136$.

The same 12 varieties were included in the rod-row trial with 72 varieties sown in the same year. The plan of this experiment was similar to that to be described for the trial sown in 1923, except that check plats occurred only in every tenth row. Most varieties were replicated[3] six times, but 1 of the 12, *viz.*, 3737, was replicated only five times. The 12 varieties, corresponding to those in the broadcast plats, occurred in adjacent rows in each block of replications. The error for the mean yield of a variety over 3 years was in this case .057.

The broadcast plats yielded more than the rod rows owing to quicker establishment in the first year. After the first year yields in the two types of plat seem to be directly comparable. Table 2 shows the mean yield of the 12 varieties in each year.

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[3] We have used the word "replications" to mean the total number of plats of a variety, in this case six.

TABLE 2.—*Average yield of 12 varieties in each trial and year.*

	Harvest year				
	1st	2nd	3rd	4th	5th
Broadcast plats, sown Sept. 1920	3.09	2.08	1.35	—	—
Rod rows, sown Sept. 1920	1.42	2.12	1.42	1.86	1.15
Rod rows, sown Sept. 1923	—	1.94	1.82	1.93	—

Over the 3 years, 1921–23, the mean yield of the broadcast plats was greater than that of the rod rows by 0.49 ton per acre. The average yield for each variety is shown in Table 3. The last column gives the differences in yield observed for corresponding varieties in the two sets of plats after making allowance for the 0.49 ton per acre by which broadcast plats exceed rod rows. Since the two sets of plats are entirely distinct they must be uncorrelated and the error of a difference between them is given by $E_d = \sqrt{E_1^2 + E_2^2}$ where E_d is the standard error of a difference and E_1 and E_2 are the standard errors for plats and rows, respectively. The distribution of the differences relative to their standard error is shown in Table 4.

TABLE 3.—*Average yield of 12 varieties over 3 years (1921–23) in two separate trials, one of broadcast plats, the other of rod rows.*

Variety	Yield of		Dfference plats — (rows + .49)
	Plats	Rows	
4003	2.31	1.87	—.05
4022	2.50	1.81	0
1676	1.96	1.81	—.34
4031	2.36	1.77	.10
1777	2.34	1.77	.08
4059	2.18	1.77	—.08
4032	2.24	1.68	.07
3937 U. S.	1.96	1.66	—.19
4055	2.07	1.63	—.05
4036	2.06	1.41	.16
4051	1.74	1.31	—.06
4001	1.99	1.30	.20
Standard error (E)	.14	.057	.15
Standard error of a difference (Ed)	.20	.081	—
Mean of 12 varieties	2.14	1.65	—

TABLE 4.—*Frequency of differences shown in Table 3 relative to their standard error.*

	<E	>E<2E	>2E<3E
Frequency observed	8	3	1
Frequency expected	8	3.4	.6

The distribution to be expected if the differences are due to random error is also given, calculated from a table of the normal probability integral. Further calculation of a test of goodness of fit is unnecessary to demonstrate the closeness of agreement. Hence, it is concluded that the two tests of timothy varieties in broadcast plats and in rod rows agree with each other to precisely the extent which would be expected of them having regard to the experimental errors of each and assuming that varieties yield similarly in both types of trial.

ROD ROWS SOWN IN 1923

Thirty-nine varieties sown in rod rows in 1923 were harvested in 1925, 1926, and 1927. There were 10 replications, and variety 4051 was sown as a check in every fifth row. The varieties were sown in the same order in each replication, but whereas in half of the replications the checks occurred between the 4th and 5th, 8th and 9th, etc., varieties, in the other half they occurred between the 2nd and 3rd, 6th and 7th, etc., varieties.

SOIL HETEROGENEITY AND SYSTEMATIC REPLICATION

The trial covered a total area of 0.7 acre, 380 feet from east to west and 78 feet from north to south. There was a slight gradient rising toward the north. In previous years when cereal variety trials had been conducted in this area, rod rows running north and south were used and the area was considered to be fairly uniform. Because the present trial had to stay in the ground for 4 or 5 years, it was more convenient for purposes of cultivation between the rows to place them in an east-west direction. The result was to disclose a severe fertility gradient. A band of fertile soil of variable width, but roughly about one-third of the width of the whole area, lay along the southern side and yielded around 2 tons per acre. From here the fertility decreased towards the north yielding only around 1 ton per acre along the north edge and being least fertile in the western half of this edge. Rod rows placed as in this trial were subject to the maximum possible variation from plat to plat owing to changes in soil fertility; whereas, if placed north and south no plat would have lain wholly on the poorest ground.

Owing to the systematic arrangement of varieties, the mean yields of varieties cannot be considered to be directly comparable. That direct comparison between varieties would lead to serious errors may be demonstrated by dividing the check rows into 11 groups of 10, each group corresponding approximately to the 10 rows of a variety. When this is done it is found that eight groups differ from the mean of all by an amount greater than their standard error and that five groups differ by more than twice their standard error. If each group of 10 rows were a fair sample only, 3.7 and 0.6 groups should be expected to differ to those extents, respectively. We have here an example where systematic replication has signally failed to sample the soil area effectively. Scarcely any other arrangement within blocks of replications could have given so great differences; or could have caused the average standard deviation of 12 varieties to be .37 ± .03 with a range from .29 to .53, whereas, that of 25 varieties was .20 ± .01 with a range from .12 to .27.

Some method of adjusting varietal yields must be resorted to if they are to be at all comparable.

ADJUSTING PLAT YIELDS

For field trials of this type three methods of adjusting observed yields have received some measure of acceptance, as follows:

1. To adjust yields by regression on a moving average as proposed by Richey (6, 7).[4] Richey, himself, gave as one of "the fundamental concepts on which the proposed method is based . . . that the mean yield of any one seed class is a fair measure of its productiveness". But it has been noted above that the mean yield of each variety is not a fair measure, and this is the reason why adjustment is required. In other words, Richey's method of adjustment is only applicable when each set of replications is a fair random sample. It sought to do what may now be done more efficiently in a "randomized block" experiment by taking out the sum of squares due to blocks in an analysis of variance (Fisher, 1).
2. To estimate "theoretical checks" for each varietal plat by regressions on the observed check plats as put forward by Hayes (2). With certain minor alterations this is probably the most efficient way to use check plats, but the gain over method 3 is insufficient to warrant the amount of labor involved.
3. To estimate theoretical checks by simple grading from one check to the next, as has been the common practice in Cornell cereal variety trials (Love and Craig, 5). The third method was used in the present study and proved highly efficient. The difference between the theoretical check and the observed yield for each row was added to the mean of all checks to give the adjusted yield of each row.

There has always been some doubt concerning the validity of using theoretical checks in comparing varieties. Stadler (8) pointed out that the efficiency of adjustment depends upon the correlation between expected and actual yields, and that this correlation is a measure of the soundness of adjustment. If no adjustment be made then the most accurate comparison available is between neighboring plats. The correlations[5] obtained between expected and actual yields as compared to correlations between adjacent rows are shown in Table 5. They suggest that comparisons to theoretical checks may be, if anything, more accurate than between adjacent rows.

TABLE 5.—*Correlation between actual and theoretical yields per row compared to correlation between adjacent rows.*

	1925	1926	1927
Correlation between actual and theoretical yields per row	.76±.02	.81±.02	.78±.02
Correlation between yields of adjacent rows	.59±.03	.77±.02	.80±.02

Several things are gained by this adjustment of observed yields. Not only are the varietal yields rendered comparable, but their errors are also greatly reduced. The average standard deviation of adjusted yields is 33% less than that of actual yields. Secondly, whereas standard deviations of observed yields of each variety tend to be correlated in successive years owing to each variety having the same plats each year, the absence of correlation between standard deviations of adjusted yields per variety in 1925 and subsequent years suggests that adjustment has discounted systematic effects of soil heterogeneity (Table 6). Thirdly, the standard deviations per variety of adjusted yields show normal variation to an extent not greatly different from that which is to be expected for small samples of 10 rows if the true standard deviations of all are the same (Table 7). It is therefore permissible to use an average standard deviation calculated from all the data as an estimate of error which may be applied throughout the experiment, and such estimate will have sufficient accuracy to be used with a table of the normal deviate instead of with the table of *t*. This would not be justifiable if observed yields were to be considered, because standard deviations per variety are then extremely variable and differ from each other.

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[4] Numbers in parenthesis refer to "Literature Cited," p. 128.

[5] To eliminate varietal effects, the figures used for correlation are the differences of the row yields from the mean of their variety.

TABLE 6.—*Correlations between standard deviations of varieties in successive years.*

	1925 and 1926	1925 and 1927	1926 and 1927
Correlation of standard deviations of actual yields........	.47	.56	.55
Correlation of standard deviations of adjusted yields......	.05	.06	.48

$n'=37$

TABLE 7.—*Standard deviations of standard deviations per variety for adjusted yields compared to that to be expected on the theory of random sampling.*

	1925	1926	1927
Average standard deviation of 36 varieties (σ).................	.179±.006	.172±.006	.326±.012
Expected standard deviation of standard deviations per variety estimated from 10 rows ($\sigma/\sqrt{20}$)................	.0400±.0014	.0385±.0014	.0729±.0027
Observed standard deviation of standard deviations per variety...	.0405±.0047	.0509±.0059	.118±.014
Difference..................	.0005+.0049	.0124±.0061	.045±.014

Hopkins (3) has discussed, in the light of modern statistical theory, the defects of systematic arrangement in field experiments of this type. Table 6, however, is taken to indicate that in adjusting yields we have, to a large extent, eliminated the systematic errors due to the interaction of soil heterogeneity with the systematic arrangement of varieties. It has, therefore, been considered permissible to proceed to analyze the adjusted yields for 1925 and 1926 as though the order of sowing were random.

Timothy yields show a tendency to increase in variability in the later harvest years (Table 8). Variability of observed yields shows a similar change. Increased variability of the check may, therefore, be responsible for introducing some correlation into the standard deviations per variety for 1926 and 1927. However, this is unlikely to introduce a systematic error into the estimates of varietal yield.

TABLE 8.—*Average standard deviations of adjusted yields for each harvest year.*

Harvest year	1st	2nd	3rd	4th	5th
Rows, sown Sept. 1920	.34	.17	.20	.29	.26
Rows, sown Sept. 1923	—	.18	.17	.33	—
Plats, sown Sept. 1920	.25	.47	.28	—	—

ANALYSIS OF THE DATA

One variety, Aberystwyth Bd 10, was peculiarly subject to variation. In all 3 years it showed standard deviations much greater than any other variety, *viz.*, .33, .32, and 1.35 in 1925, 1926, and 1927, respectively. An average standard error is therefore not applicable to this variety. It has been excluded from the present study throughout.

Simple inspection of the yield figures shows that the three Aberystwyth varieties behaved differently from all others in ability to continue yielding in later years. They were the highest yielding varieties in 1925 and the lowest in 1926 and 1927. The differential interaction of these varieties with harvest years is so obvious that it requires no mathematical analysis to expose it. It therefore appears more profitable to limit the analysis to the remaining 36 American varieties. We may then test whether there is also within this group any differential interaction with successive years.

In using Fisher's method for the analysis of variance, the assumption is implied that the experimental errors applicable to all varieties in all years are of similar magnitude so that an average error may be valid as an estimate of error for the whole experiment. It has been shown that this is true for the years 1925 and 1926, but that in the year 1927 variation, and therefore experimental error, was considerably greater than in previous years. It therefore seems advisable, for the greatest accuracy, to confine the analysis to the first 2 years.

Reduction of degrees of freedom owing to yields having been adjusted on the check is represented by the loss of all degrees of freedom which could otherwise have been assigned to the check rows. For the purpose of the analysis we have only 35 independent varieties. Table 9 presents the analysis of variance for 36 varieties for 2 years. The respective mean squares are either so obviously different from, or so similar to, the mean square for error that calculation of values for z would serve no useful purpose. The analysis shows that differences between varieties are decidedly significant, and that there was no interaction between varieties and years, that is, varieties showed substantially the same order of yield in both years. The mean square for the error of the experiment is given as .0307. Since each varietal yield is obtained from the mean of 20 rows, the square of the standard error of the mean yield of a variety is given by dividing this by 20 ($E_{20}^2 = .0307/20$). This must then be multiplied by 2 to give the square of the error of a difference between two means (dE_{20}^2). We thus have $dE_{20} = \sqrt{.00307} = .0554$ which is the error quoted in Table 12 for the difference between the mean yields of two varieties over the 2 years 1925 and 1926.

TABLE 9.—*Analysis of variance of yields of 36 varieties over 2 years, one seeding.*

	Degrees of freedom	Sums of squares	Mean square
Between varieties	34	11.610	.3415
Between years	1	4.776	4.776
Interaction of varieties and years	34	1.217	.0358
Remainder	630	19.328	.0307
Total	699	36.931	

Although certain objections have been pointed out against combining the results for the third year with the rest, an analysis of variance for all 3 years has nevertheless been made (Table 10). The main object in view was to see if any differential reaction with the third year (the fourth harvest year) could be detected. The results are closely similar to those of Table 9 and no interaction of varieties and years can be demonstrated. Using the average mean square for error given by this table (.0562), we obtain for the error of a difference between the means of two varieties $dE_{30} = .0612$. By including the results from the third year, our estimates of yield have been made less accurate than when the results from only 2 years are used. It seems, therefore, that in yield trials with timothy it is not worth while to record yields for more than the second and third harvest years unless it be suspected that some varieties may change their relative yields in later years and it is desired to test this point.

TABLE 10.—*Analysis of variance of yields of 36 varieties over 3 years, one seeding.*

	Degrees of freedom	Sums of squares	Mean square
Between varieties	34	15.901	.4677
Between years	2	4.714	2.357
Interaction: varieties vs. years	68	4.341	.0638
Remainder	945	53.064	.0562
Total	1,049	78.020	

The possible existence of differential interaction between varieties and years was further tested for two separated seedings and up to five harvest years by taking all the results for the 12 varieties which were sown in both the 1920 and 1923 series of rod rows and combining them into a single analysis of variance. For this analysis there are 11 independent varieties; 10 of these were replicated six times and 1 of them five times in each of the 5 years 1921–25, and all were replicated 10 times in the 3 years 1925–27. There are thus available for the analysis 655 independent row yields giving 654 degrees of freedom.

Table 11 shows that here again for these 12 varieties in 8 harvest years no differential interaction can be detected.

TABLE 11.—*Analysis of variance of yields of 12 varieties over 8 years, two seedings.*

	Degrees of freedom	Sums of squares	Mean square
Between varieties	10	13.942	1.394
Between years	7	50.901	7.272
Interaction: varieties vs. years	70	3.992	.0570
Remainder	567	36.077	.0636
Total	654	104.912	

The results from the broadcast plats might also have been incorporated in Table 11, but it has already been shown by a more elementary method that they too fall into line.

These data were originally analyzed in 1927–28 along the lines of Engledow and Yule's (9) standard deviations due to ground and to weather, σ_g and σ_w, and were used to trace the relation between these and other methods then accepted in America for estimating the errors applicable to experiments over several years. It seems worthwhile to study the relation of the parts in the analysis of variance to the older statistics. It may be of use to any readers who are still in process of becoming acquainted with the newer methods if these connections are pointed out.

The variance due to ground (σ_g^2) in the analysis of Engledow and Yule corresponds approximately to the mean square for remainder, or error of the experiment, in the analysis of variance. The variance due to weather (σ_w^2) corresponds approximately to the variance attributable to interaction between varieties and years. The latter is not, however, the same as the mean square for interaction. This is composed of the variance due to interaction multiplied by a factor, which depends upon the number of plats of each variety in each year, plus the mean square for error. (Cf. Fisher (1), Table 39.) In this form it can be compared by the z test to the mean square for error to determine whether the variance due to interaction may be significant. The variance due to interaction may be calculated from it if desired.

Similarly, if it seemed desirable to estimate average varietal differences over several years as compared to an error which took cognizance of changes in relative yields in different years (Stadler (8) and Engledow and Yule (9)), a comparison by the z test of mean square between varieties to mean square for interaction would indicate the significance of varietal differences under these conditions. But the mean square for interaction would estimate the desired error directly only if it were calculated from only one figure for yield of each variety in each year.

Of the older methods for estimating the error of mean yields over several years, the method proposed by Hayes (2) averages the annual variances. It corresponds to σ_g, but it gives no indication of changes in relative yields from year to year. The method employed by Love (4) uses as error the interaction between varieties and years. It is a composite error due partly to experimental error and partly to changes in the different years. It thus considers the average value of varietal differences over a number of years; but it uses only the mean per variety per year, ignoring data from replications within each year, and considers only two varieties at a time. It thus discards much of the information available for a more accurate estimate of the true error.

EXPERIMENTAL ERROR OF TIMOTHY PLATS

If rod rows of timothy be harvested in their second and third harvest years, it is indicated by Tables 2 and 8 that the standard error for a single row is about 9%. Although not strictly comparable, being in different fields, it is surprising to note that the broadcast plats, 16½ feet by 49½ feet, showed a higher error, namely, 8 to 20%.

SUMMARY

1. The paper reports the results of a varietal yield trial with 39 varieties of timothy sown in September 1923 and harvested in 3 years, 1925-27. Plats were in the form of rod rows. The yields obtained are given in Table 12.

TABLE 12.—*Annual and average yields (adjusted by differences from checks) of 39 varieties of timothy, 1925–27; yield in tons per acre.*

	1925	1926	Average 1925 and 1926	Successive differences*	1927	Average 1925–27
Standard error of a difference between two varieties....	.080	.077	.0554	—	.146	.0612
Difference required to give P = .05......	.16	.15	.11	.11	.29	.12
Difference required to give P = .01......	.21	.20	.14	.14	.37	.16
Variety 4059..	2.23	1.98	2.10	—	1.93	2.05
4059 H. R..	2.22	1.93	2.08	.02	1.93	2.02
6408.......	2.16	1.96	2.06	.02	1.74	1.95
4081.......	2.19	1.91	2.05	.01	1.97	2.02
1777.......	2.10	1.91	2.00	.05	1.97	2.00
4022.......	2.07	1.92	2.00	—	2.16	2.05
4078.......	2.07	1.92	2.00	—	2.06	2.02
4032.......	1.99	1.98	1.98	.02	2.09	2.02
9349.......	2.05	1.92	1.98	—	1.95	1.97
1676.......	2.12	1.83	1.98	—	1.96	1.97
4123.......	2.11	1.83	1.97	.01	2.01	1.98
9400.......	2.10	1.84	1.97	—	1.99	1.97
10358......	2.06	1.84	1.95	.02	1.79	1.89
4031.......	1.97	1.90	1.94	.01	2.09	1.98

*Differences between any two varieties can be easily obtained from this column by addition, following Engledow and Yule.

TABLE 12.—*Concluded.*

	1925	1926	Average 1925 and 1926	Sucessive differences*	1927	Average 1925–27
Van Doren.	2.06	1.79	1.92	.02	1.99	1.95
1777 Reed..	1.95	1.89	1.92	—	1.87	1.90
6807.......	2.03	1.80	1.91	.01	2.09	1.97
9743.......	1.98	1.83	1.90	.01	1.72	1.84
9327.......	1.97	1.81	1.89	.01	2.02	1.93
4055.......	1.93	1.82	1.88	.01	1.95	1.90
4079.......	1.93	1.81	1.87	.01	1.83	1.85
4003.......	1.95	1.78	1.86	.01	2.01	1.91
9647.......	1.87	1.84	1.86	—	1.86	1.86
3937 U. S...	1.86	1.85	1.86	—	1.83	1.85
St. Coll. 1–22–54–54	1.96	1.75	1.86	—	1.81	1.84
St. Coll. 30–38.......	1 91	1.77	1.84	.02	1.79	1.82
St. Coll. 2–46–46....	1.97	1.71	1.84	—	1.73	1.80
4036.......	1.90	1.77	1.84	—	1.87	1.85
St. Coll. 7–4–43–35..	1.92	1.70	1.81	.03	1.71	1.78
4001 H. R..	1.90	1.68	1.79	.02	1.76	1.78
No. Ridgeville.....	1.86	1.71	1.78	.01	1.86	1.81
1777 H. R..	1.86	1.71	1.78	—	1.74	1.77
4051 (Check)	1.78	1.68	1.73	.05	1.79	1.75
Pine Tree..	1.57	1.59	1.58	.15	1.72	1.63
4001.......	1.64	1.50	1.57	.01	1.48	1.54
4051 H. R..	1.60	1.50	1.55	.02	1.69	1.60
Aberystwyth Bd 11†.......	2.20	1.39	1.80		1.58	1.72
Aberystwyth Bd 12†.......	2.36	1.51	1.94		1.55	1.80
Aberystwyth Bd 10‡.......	2.31±.104	1.48±.101	1.94±.073		1.91±.43	1.90

*Differences between any two varieties can be easily obtained from this column by addition, following Engledow and Yule.

†Late-maturing varieties cut about 3 weeks later than the rest.

‡Average errors are not applicable to variety Bd 10.

2. With the exception of three varieties obtained from Aberystwyth, Wales, the relative yields of varieties were the same, within the limits of experimental error, in all 3 years. The Aberystwyth varieties gave the greatest yields in 1925 and the lowest in subsequent years.

3. Twelve of the 39 varieties were also grown in two other trials sown in 1920; one used rod rows and was harvested over 5 years, 1921–25; the other used broadcast plats, 16½ feet by 49½ feet, and was harvested in 3 years, 1921–23. It has been shown that the yields of these 12 varieties agreed in all three trials as closely as they could be expected to do having regard to the experimental errors of the trials.

4. Rod rows showed least variability in the second and third harvest years. In these years the standard error for a single row was about 9%. It is recommended that in rod-row trials of timothy only the yields in these 2 years should be recorded, unless it be desired to investigate ability to maintain yields in subsequent years. The error observed for the broadcast plats was 8% in the first year and about 20% in the second and third years.

5. The rod-row trial sown in 1923 had 10 replications of each variety, but these were arranged in a systematic manner. The trial presents a case in which the effects of soil heterogeneity were extremely marked because the long narrow plats (rod rows) lay along, instead of across, the fertility gradient, and in which, because of the systematic arrangement of replications, the mean yields of varieties were not directly comparable. The position was, however, retrievable by the use of check plats which occurred in every fifth row. Reasons have been presented by which it was deemed permissible to apply Fisher's analysis of variance to yields adjusted by relation to the checks.

6. The relation to parts in the analysis of variance of older statistics which have been used to estimate the errors of experiments extending over several years has been indicated.

LITERATURE CITED

1. Fisher, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd, Ed. 3. 1931.
2. Hayes, H. K. Control of soil heterogeneity and use of the probable error concept in plant breeding studies. Minn. Agr. Exp. Sta. Bul. 30. 1925.
3. Hopkins, J. W. Effect of rate of seeding upon comparisons of varieties of oats. Can. Jour. Res., 7:1–50. 1932.
4. Love, H. H. Student's method for interpreting paired experiments. Jour. Amer. Soc. Agron., 16:60–68. 1924.
5. ————, and Craig, W. T. Methods now in use in cereal breeding and testing at the Cornell Agricultural Experiment Station. Jour. Amer. Soc. Agron., 16:109–127. 1924.
6. Richey, F. D. Adjusting yields to their regression on a moving average as a means of correcting for soil heterogeneity. Jour. Agr. Res., 27:79–90. 1924.
7. ————. The moving average as a basis for measuring correlated variations in agronomic experiments. Jour. Agr. Res., 32:1161–1175. 1926.
8. Stadler, L. J. Experimental error in field plot tests. Proc. Intern. Plant Sci. Congr., Ithaca (1926):107–127. 1929.
9. Engledow, F. L., and Yule, G. U. Principles and Practice of Yield Trials. London: Empire Cotton Growing Corp. 1928. (Page 79.)

THE USE OF SMALL AMOUNTS OF NITROGEN FOR CORN IN ADDITION TO PHOSPHORUS AND POTASSIUM[1]

S. R. Miles[2]

This paper deals principally with a study in Indiana comparing phosphate-potash fertilizers with complete fertilizers for corn when relatively small amounts of nitrogen are used.

Normally about 100,000 tons of fertilizer are used annually for corn in Indiana. More than two-thirds of this is complete goods, and the trend has been toward the use of a larger proportion of complete fertilizers. This is despite the fact that the Experiment Station (10)[3] has for years recommended phosphate-potash fertilizers for corn under most conditions.

The National Fertilizer Association (5) reports that in the middle-western states in general the trend has been toward complete fertilizers for corn, and in several states most of the fertilizer now used is complete.

In Indiana, most corn fertilizer is 2–12–6, or something similar, and it is used at rates which give 2 to 6 pounds of nitrogen per acre. Practically all the fertilizer is applied at planting time and it is drilled continuously in the corn rows or is dropped in or near the hills. Similar methods are used and similar amounts of nitrogen are applied in most of the corn belt wherever complete fertilizers are used. In general, these practices have been profitable.

The present study compares the prevalent practice of using complete fertilizers for corn with the use of similar fertilizers from which the nitrogen has been omitted and in which only the phosphorus and the potassium have been included. It should be very definitely kept in mind that, except where otherwise specifically stated, the results are for tests in which only small amounts of nitrogen, 2 to 6 pounds, were applied per acre, and in which the fertilizer was applied at planting and was drilled continuously in the rows or was dropped near the hills.

THE EXPERIMENTS

Complete fertilizer has been compared with phosphate-potash fertilizer for corn on several of the most important soil types in Indiana. The only important corn soils which have not been included are the prairie soils and the creek and river bottom soils. The fertilizer has been drilled in the rows or dropped near the hills at planting time in amounts which gave 2 to 6 pounds of nitrogen per acre.

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[2] Assistant in Agronomy. The writer gratefully acknowledges his indebtedness to Prof. A. T. Wiancko for kindly help and advice and to the following men who, in addition to the writer, conducted the experiments on which this study is based: G. P. Walker, R. R. Mulvey, O. B. Riggs, M. M. Diehm, and Frank Moser.

[3] Reference by number is to "Literature Cited", p. 137.

Twenty-three different experiments have been conducted for 1 to 9 years. In each of four experiments there has been only one plat-pair where NPK and PK could be compared each year. In each of the other 19 experiments 2 to 51 comparisons were possible each year. In all the tests a total of 261 comparisons were possible. Tests by Abbott and Conner (1) are omitted from most of this study because dried blood was used as the nitrogen carrier, while in the 23 tests studied inorganic nitrogen was used.

The locations were widely scattered over the state. The analyses of the complete fertilizers were 2–12–6, 4–12–6, 2–12–8, 2–16–8, 2–12–12, 3–12–12, 4–12–12, and 4–10–6. The PK fertilizers were the same except for the omission of the nitrogen. The nitrogen was usually supplied half by nitrate of soda and half by ammonium sulfate. The phosphorus and potash were supplied by 16% or 20% superphosphate and by 50% muriate of potash, respectively.

Ninety to 200 pounds of fertilizer were applied per acre. In five experiments the fertilizer was applied near the corn hills, but in all the other experiments the fertilizer was drilled in the row while the corn was generally in hills. In some cases both the NPK and the PK plats were side-dressed with nitrate of soda when the corn was 12 to 24 inches high. A majority of the tests were never repeated on the same piece of land. The area harvested varied from 0.01 to 0.05 of an acre.

RESULTS

Table 1 is a summary of the yield results of all 23 experiments. The yields are stated as bushels per acre increase or decrease from the use of 2 to 6 pounds of nitrogen per acre in addition to the phosphorus and potash. The PK treatments produced an average increase of 6.7 bushels per acre.

Stands of corn were not affected by the nitrogen so that yield differences are not due to differences in stands.

The only 2 years when nitrogen gave an increase in yield in experiment 20 the NPK treatment decreased the yield as compared with no fertilizer, but the NPK plats yielded slightly more than the PK plats.

Odds for the averages were determined by the use of Student's method as explained by Love (3) and Love and Brunson (4).

An examination of column K shows that nitrogen increased the yield in only 4 of the 23 experiments. These average increases are 0.2, 0.2, 1.3, and 2.7 bushels and the largest odds are only 3 to 1 that the true average for similar conditions would show any increase at all. The largest increase represents only 1 year. The next largest increase, 1.3 bushels, not only has low odds, but the test, although of 9 years duration, was not replicated, the two plats compared were some distance apart, and only four different pieces of land were used. Thus it is evident that none of the increases from nitrogen is significant.

Eighteen experiments show decreased yields due to the use of nitrogen. While the odds indicate that some of these decreases have little significance, others of the decreases have high significance.

TABLE 1.—*Effects on corn yields of 2 to 6 pounds of nitrogen per acre applied at planting time in addition to phosphorus and potash.*

Exp. No.	Increase or decrease due to nitrogen, bushels per acre									Unweighted means	Odds
	1923	1924	1925	1926	1927	1928	1929	1930	1931		
A	B	C	D	E	F	G	H	I	J	K	L
1	+0.9	—3.0	+0.2	—0.2	—0.6	+0.7	+1.7	+0.3	—3.8	—0.4	2.7
2					+3.0	—2.1	0.0	—0.1		+0.2	1.3
3						—9.9	—3.1	—1.0		—4.7	8.1
4								—1.2	—2.0	—1.6	2.8
5									—3.0	—3.0	4.5
6							+7.7		—10.1	—1.2	1.2
7							—4.2	+2.8	—1.8	—1.1	2.1
8							—2.5			—2.5	9.0
9								—2.3		—2.3	66.0
10									—2.9	—2.9	332.0
11							+1.0	+0.7	—7.6	—2.0	3.4
12					—7.5	—7.5	+5.0			—3.3	2.9
13							—0.8	+1.5	—0.6	0.0	
14					—3.8		—7.4	+2.9		—2.8	3.4
15					+2.7					+2.7	2.8
16			+2.2	—5.1	—0.3	+3.6	+0.9	+0.2	—2.2	—0.1	1.0
17			+7.6	+4.5	—6.4	—2.5	—6.3	—1.9	+0.3	—0.7	1.7
18									—8.7	—8.7	46.0
19					—0.3	—2.0	+0.5	+2.4		+0.2	1.5
20					+1.2	—0.3	—0.2	—2.1	+0.5	—0.2	1.7
21					—6.9	+1.7	—1.2	—5.0		—2.8	6.7
22						—0.1		—1.3		—0.7	2.1
23	+7.1	+2.6	—3.5	+4.5	+0.7	—1.1	+6.2	—8.7	+4.2	+1.3	3.0
Means....	+4.0	—0.2	+1.7	—0.3	—0.8	—1.6	—1.4	—1.5	—3.3	——*	
Plat-pairs	2	2	5	5	15	17	79	69	67	261 (total)	

*See Table 2.

There are several ways to calculate the mean for all 261 comparisons in the 23 experiments. In Table 2 are shown means of the means for the 23 experiments, unweighted and weighted; means for all 9 years, unweighted and weighted; and means for the last 5 years, unweighted and weighted. Means are shown for the last 5 years because the data in the first 4 years are very meager, there being only two to five comparisons each year. Five of the six means in Table 2 are surprisingly close, varying from 1.6 bushels decrease to 1.9 bushels decrease, and all five have high odds. The weighted mean for all 9 years is probably a fair one to select as representative of all tests. It is concluded, therefore, that under a wide variety of conditions during 9 years, the use of 2 to 6 pounds of nitrogen per acre in addition to phosphorus and potash decreased the corn yield an average of 1.8 bushels per acre.

TABLE 2.—*Means of data in Table 1.*

	Mean bushels per acre	Odds
Means of the means for separate experiments (means of means in col. K, Table 1):		
Unweighted	—1.6	727.0
Weighted* (261 plat-pairs)	—1.8	——†
Means of all nine annual means:		
Unweighted	—0.4	2.4
Weighted* (261 plat-pairs)	—1.8	——†
Means of last five annual means:		
Unweighted	—1.7	132.0
Weighted*	—1.9	——†

*Weights are number of plat-pairs.
†Odds not calculated but high.

Experiments 8, 9, and 10 deserve special attention. These tests were conducted on 10 to 17 farms each year with triplicate comparisons on each farm. These farms were widely distributed over the northeastern third of Indiana and the soil types were those on which a very large proportion of Indiana's corn is grown. In addition, the corn was planted and the fertilizer applied with planters which farmers in general are using. In each of the 3 years, 1929 to 1931, 3 to 6 pounds of nitrogen caused a yield loss of more than 2 bushels of corn per acre. (See Table 1.) The average yield loss for 3 years and 38 farms was 2.6 bushels per acre with the high odds of 705 to 1.

Trost (unpublished data) used the Hoffer test for nitrogen on corn stalks from some of the PK and NPK plats in the Indiana experiments. He found that in August and early September there was less nitrogen in the corn stalks from plats which received NPK at planting than in the stalks from plats which received only PK.

An analysis of results under particular conditions will now be made.

The means of columns in Table 1 permit a study of nitrogen effects in different seasons. The means of the first 4 years have little significance due to the paucity of data. In every one of the last 6 years, 1927 to 1932, nitrogen has reduced the corn yield.[4] The weather during these 6 years represented a great range, including wet and very dry seasons, also cool and hot seasons. It seems, therefore, that nitrogen is likely to cause yield losses in a great majority of years.

Table 1 is arranged with the heavier soils at the top and the sandier soils at the bottom. This table and other more detailed studies of the effect of soil texture on the results from nitrogen indicate that the yield losses from the use of nitrogen are not correlated with soil texture.

A careful study of the original data leads to the conclusion that the likelihood of yield loss from the use of nitrogen is not correlated with the level of yields obtained.

The results indicate that nitrogen reduced the corn yields whether or not stable manure was used for the corn.

The data have also been studied to see whether the effect of nitrogen applied in the row or hill at planting was dependent upon the use of nitrate of soda as a side-dressing when the corn was 12 to 24 inches high. The data are rather few, but there is no indication that nitrogen side-dressings changed the effect of nitrogen used at planting.

No correlation was apparent between the amount of nitrogen used per acre at planting and the effects of the nitrogen on yields so long as not more than 6 pounds of nitrogen were applied per acre.

Are the effects of nitrogen used at planting dependent on whether a legume immediately preceded the corn crop? The data indicate that when corn followed a *good* stand of red clover, sweet clover, or alfalfa, nitrogen resulted in an average increase in yield of 1.3 bushels. The odds are very low, only 4 to 1, that under similar conditions any increase could be expected. When corn followed a *poor* stand of red clover, sweet clover, or alfalfa, nitrogen depressed the yield slightly, but the depression was less than when the corn followed soybeans or a non-legume.

SMALLER AND LARGER AMOUNTS OF NITROGEN

Thus far the discussion has been confined to consideration of the effect of small amounts of nitrogen, 2 to 6 pounds per acre. A comparison will now be made of small amounts of nitrogen with larger amounts. In none of the tests where such applications can be compared did the small application increase the yield. On the average, 3 pounds of nitrogen decreased the yield 1.8 bushels (odds, 163:1). The larger amounts of nitrogen, averaging about 9 pounds per acre, gave rather consistent yield increases. The average increase was 2.5 bushels (odds, 44:1).

It should be very definitely noted that the larger applications of nitrogen were made by increasing the per acre applications of all three fertilizer elements and not by increasing the proportion of nitrogen in the fertilizer. For this reason it was found, when viewed from a standpoint of profit per acre, that the complete fertilizer application which supplied less nitrogen was more profitable than that which supplied more nitrogen. This was largely due to the operation of the law of diminishing returns upon the yield increases due to the phosphorus and potash. The PK fertilizer gave the greatest profit.

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[4] The data for 1932 were not ready to include in Table 1, but results are similar to those in the preceding 5 years.

Abbott and Conner (1) report work in Indiana for 4 years, 1905 to 1908, which showed that an increase in the *proportion* of nitrogen in the fertilizer applied in the row or hill gave very little increase in the yield of corn. An average of 180 pounds of fertilizer per acre was used in 15 tests in 11 counties. The fertilizers were 0–8–2, 2–8–2, and 8–8–2. About 4 pounds of nitrogen from dried blood increased the corn yield 0.9 bushel and an additional 10 pounds of nitrogen further increased the yield only 0.6 bushel. The increase in the proportion of nitrogen thus had practically no effect and was certainly uneconomical.

New tests, which are now in progress in a limited way, are needed to determine more definitely whether a larger proportion of nitrogen than is now generally used will give better results.

SOURCE OF NITROGEN

In the 23 experiments which indicate that usually nitrogen used at planting depresses yield, only inorganic nitrogen was used. Might different results have been secured from organic nitrogen? The only evidence on this question comes from comparing the recent work with the work of Abbott and Conner (1), who used dried blood. They secured increased yields of 0.9 bushel from 4 pounds of nitrogen, and 1.5 bushels from 14 pounds of nitrogen. Neither of these increases was very signficant statistically. The recent tests with inorganic nitrogen show an average yield decrease of 1.8 bushels per acre from 2 to 6 pounds of nitrogen. Apparently there is little difference in the effect on yield of the two forms of nitrogen used alone. It is only a conjecture as to whether a combination of both would prove superior to either alone for use at planting time.

EFFECT OF NITROGEN ON EARLY GROWTH

In 1932, a special test was conducted on three farms to determine the effect of each element on the early growth of corn. One hill was unfertilized, the next received 0–12–0, the next 0–12–8, the next 2–12–8, and the fifth 5–12–8. The applications were 125 pounds per acre near the hills. There were as many as 16 replications per farm. The results at one farm are shown in Table 3. At 5 to 7 weeks after planting, phosphorus alone had increased the height of the corn 9 or 10 inches. Adding potash resulted in another increase which was about one-third as great as the increase from phosphorus. Two or 5% of nitrogen gave a further increase in height, but the increase from nitrogen was less than that from either phosphorus or potash. A nearly average replicate of this test is shown in Fig. 1.

At the farm where this test was conducted moisture conditions were very good while the corn was growing. The soil was Crosby

TABLE 3.—*Heights of corn plants with hill applications of different fertilizers, Crosby silty clay loam soil, Farmland, Indiana, 1932.**

No. of days after planting	Average height in inches				
	0	0–12–0	0–12–8	2–12–8	5–12–8
36	25.5	34.2	37.1	38.8	39.6
49	40.9	51.5	55.7	57.7	59.7

Increase in height for each additional element or increment, inches

	P	K	N, 2%	N, extra 3%
36	8.7	2.9	1.7	0.8
49	10.6	4.2	2.0	2.0

*Measurements were made with leaves held vertically. Hill applications of 125 pounds per acre of the following fertilizers were used: 0–12–0, 0–12–8, 2–12–8, 5–12–8. The corn was planted May 31. The figures are means of 16 three-plant hills for each treatment. All odds are high for the increases.

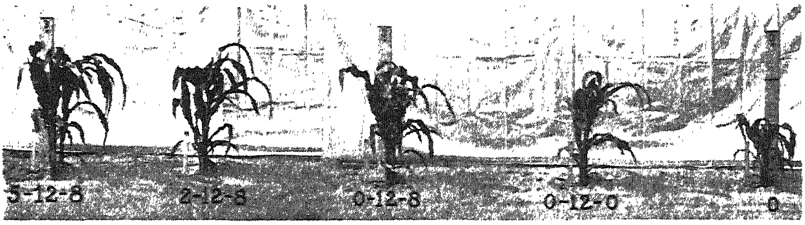

FIG. 1.—Corn on the light-colored Crosby silty clay loam soil near Farmland, Indiana, 36 days after planting in 1932. The above fertilizers were applied at planting at the rate of 125 pounds per acre near the hill.

silty clay loam. At the other two farms the season was rather dry. At one of these the test was on Crosby silty clay loam and at the other on Plainfield fine sandy loam. In each case PK produced a small height increase which was not significantly added to by nitrogen.

During the 5 years previous to this 1932 test, careful notes were made of the effects of P, PK, and NPK on the height of corn, although actual measurements were not made. Results in these 5 years were very consistently like those in 1932. From all 6 years results the following conclusions are drawn.

Except under unfavorable moisture conditions, corn fertilized with phosphate and potash in the row or near the hill grows much more rapidly than unfertilized corn. The addition of 2 to 5% of nitrogen gives only a small additional increase in height.

EFFECT OF NITROGEN ON MATURITY

Observations have also been made of the effects of nitrogen on rapidity of development and on earliness of maturity. In 6 years, nitrogen added to PK has only occasionally hastened tasseling and never to exceed one day. As indicated by the percentage of moisture in the corn at husking, maturity has not been hastened by the addition of nitrogen to PK. On the other hand, either PK or NPK has frequently considerably hastened maturity as compared with unfertilized corn.

DISCUSSION

The very common practice in Indiana and in some other corn belt states of using complete fertilizer for corn does not seem to be justified by the results of the Indiana tests reported in this paper. While the use of complete fertilizers has no doubt been generally profitable, it is very likely that on the average the omission of nitrogen would have resulted in higher yields, as well as in greater profits.

Comparatively few tests have been conducted by experiment stations in other states to compare PK and NPK fertilizers in the hill or row for corn. In most tests of such use of fertilizer for corn only complete fertilizers have been used. Through correspondence it was learned that PK and NPK have been compared for corn in a limited way in Ohio (6, 7), Wisconsin (9), Iowa (2, 8), and Illinois (results not published). Workers in other midwestern states say they have no similar tests. The results in the four midwestern states are not at variance with the results in Indiana. On the other hand, the evidence from these states tends to corroborate the results in Indiana.

In Indiana, PK fertilizers have for years been recommended for corn under most conditions (10). Largely on a theoretical basis, it has been suggested that on light-colored soils about 2% of nitrogen might profitably be included in the fertilizer when manure is not used for the corn and when this crop does not follow a legume. This suggestion appears now to be in error. In fact, under such conditions, it seems most important to omit the nitrogen, and if there is any place for small amounts of nitrogen in corn fertilizer applied at planting, it is when the corn follows a *good* stand of clover or alfalfa.

Sometimes nitrogen is included in corn fertilizer because it is believed that the nitrogen induces rapid early growth and hastens maturity. In Indiana, at least, it appears that neither effect is realized to a worth while degree.

One possible disadvantage from the use of nitrogen at planting which has not yet been mentioned is that the slight increase in the early height of corn due to the nitrogen may cause an increase in infestation by the corn borer.

SUMMARY

1. The present study compares the prevalent practice of using complete fertilizers for corn with the use of similar fertilizers from which the nitrogen has been omitted and in which only the phosphorus and the potassium have been included. The fertilizers were applied in the rows or near the hills at planting time at rates which applied only 2 to 6 pounds of nitrogen per acre.

2. The results reported are for 23 experiments of 1 to 9 years duration on most of the important corn soils in Indiana. The 23 experiments permit 261 comparisons of PK with NPK fertilizers.

3. The nitrogen resulted in an average decrease in yield of 1.8 bushels of corn per acre. The odds indicate a high significance for the decrease.

4. The nitrogen used at planting appears to have decreased the corn yield largely or entirely regardless of (a), season; (b), soil texture; (c), the yield levels; (d), the use of manure for the corn; (e), side-dressings with nitrate of soda during the growing season; or (f), whether 2, 3, 4, or 6 pounds of nitrogen were applied at planting.

5. When the corn followed clover or alfalfa, the nitrogen effect was somewhat more favorable or less unfavorable than otherwise.

6. In eight instances comparisons were made between the effects of small and larger amounts of nitrogen. In these cases an average of 3 pounds of nitrogen reduced the yield 1.8 bushels, while an average of 9 pounds increased the yield 2.5 bushels compared with PK only.

7. Limited data indicate that organic nitrogen carriers were slightly superior to inorganic carriers.

8. Phosphate-potash fertilizers considerably hastened the early growth of corn. The addition of nitrogen produced only a relatively small further increase in early height.

9. Nitrogen had little or no effect in hastening maturity.

10. In conclusion, it appears that for use with corn at planting, at least in Indiana, phosphate-potash fertilizers are preferable to fertilizers containing nitrogen in addition. This is the case when less than 6 pounds of nitrogen are applied per acre. Further research is needed to determine whether any rate, method, or time of applying nitrogen for the corn crop will be profitable.

LITERATURE CITED

1. Abbott, J. B., and Conner, S. D. Results of cooperative fertilizer tests on clay and loam soils. Purdue Agr. Exp. Sta. Bul. 155:105–111. 1912.
2. Coe, Dana G. The effects of various methods of applying fertilizers on crop yields. Soil Science, 21:127–141. 1926.
3. Love, H. H. A modification of Student's table for use in interpreting experimental results. Jour. Amer. Soc. Agron., 16:68–73. 1924.
4. ———— and Brunson, A. M. Student's method for interpreting paired experiments. Jour. Amer. Soc. Agron., 16:60–68. 1924.
5. National Fertilizer Association. American fertilizer practices. Part VII: 68–73. 1929.
6. Salter, R. M. Fertilizing the corn crop. Ohio Agr. Exp. Sta. Bul. 431:17. 1929
7. ————. Field experiments in agronomy. Ohio Agr. Exp. Sta. Spec. Circ. 38:53–57. 1932.
8. Smith, Frederick B. Some effects of methods of application of fertilizers on corn and soils. Iowa Agr. Exp. Sta. Res. Bul. 104. 1927.
9. Truog, Emil, *et al.* Fertilizer experiments. Wis. Agr. Exp. Sta. Res. Bul. 65. 1925.
10. Wiancko, A. T. Fertilizers for Indiana soils and crops. Purdue Agr. Exp. Sta. Circ. 162. 1928.

THE FIXATION OF PHOSPHATES BY SOIL COLLOIDS[1]

G. D. SCARSETH AND J. W. TIDMORE[2]

It is well known that soluble phosphates in fertilizers become relatively insoluble when mixed with soils and that only small quantities are lost in drainage waters. Most soils are deficient in available phosphorus even though the total supply of native phosphorus may be high. Many soils which have received annual phosphatic fertilization for several years show the need for further applications of phosphate in order to produce satisfactory crops. Such facts, established by the results of many investigators (1, 3, 6, 8, 9, 10, 11, 12, 16, 19, 20, 22, 24, 30)[3], show that soils possess vast capacities for fixing phosphates. Mattson (14) showed that the phosphate ion was absorbed to a considerable extent by a number of soil colloids. He noted that most absorption occurred where the silica-sesquioxide ratio was the smallest, these ratios varying from 0.55 to 3.82. Roszmann (21) reported that absorption of phosphorus by sodium and calcium soil colloids was greatest at pH values between 3.0 and 3.5. Teakle (25) has shown that different H- and OH-ion concentrations in soil solutions greatly affect the solubility of various kinds of phosphates.

It is apparent from the work of these investigators and others that different soils may vary greatly in their phosphate-fixing behavior and that the acidity of the soil, particularly the degree of calcium saturation, is of great significance in the fixation of phosphates, Although the nature and extent of phosphate fixation is not thoroughly understood, it is generally accepted that the colloidal fraction of the soil is the principal seat of the fixation. It is the purpose of this paper to present some characteristics of the phosphate-fixing properties of soil colloids extracted from soils which were derived from non-phosphatic materials in a subtropical climate. The object of this investigation was to study the effect of the chemical composition, as expressed by the silica-sesquioxide ratio, and the effect of the degree of calcium saturation of the colloids on the fixation of PO_4 from some of the common sources of phosphates.

METHODS

TYPES OF COLLOIDS USED, METHODS OF SEPARATION, AND CHEMICAL COMPOSITION

Large quantities (1,000 grams) of colloids were extracted from Lufkin, Eutaw, Oktibbeha, and Cecil clays. The results of previous studies (2, 22) showed that these soils varied widely in their physical properties and chemical compositions. The Lufkin clay was derived from a marine clay; it is grey in color, very plastic and impermeable to water, and very slightly weathered with respect to the climate. The

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[1] Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication February 20, 1933.

[2] Assistant Soil Chemist and Soil Chemist, respectively.

[3] Reference by number is to "Literature Cited," p. 150.

Eutaw and Oktibbeha clays were derived from the same type of parent material and geological formation as the Lufkin clay, but they are more highly weathered. The Oktibbeha clay, which is brownish red in color, is the most highly weathered of these three soils. The Cecil clay was derived from a granite and is very highly weathered. It is very friable and is red in color.

In order to have colloids that were low in organic matter, the soil samples were taken from the upper portion of the horizons of accumulation (Horizon B_1) in each case. They were kept moist until the colloids were extracted. The separation was accomplished by dispersing the colloid with distilled water in a barrel churn for 8 hours and supercentrifuging at a speed of 20,000 r. p. m. The Cecil soil required a small amount of NaOH for dispersion. The suspended material which passed through the supercentrifuge was used in this study. The soil material deposited on the walls of the centrifuge bowl and the residue in the churn were repeatedly dispersed and put through the centrifuge until the extracted colloidal suspension was almost clear. Each colloid was electrodialized in a Mattson three-compartment cell (13) to remove all the mobile ions. Concentration of the colloid was accomplished by electrodialysis. Throughout this study each colloid was used as a 3.75% suspension.

The colloids were analyzed to determine their silica-sesquioxide ratios. These electrodialized colloids were titrated electrometrically with NaOH and $Ca(OH)_2$ to determine their total base exchange capacities, approximate pH values, and degrees of dissociation of the acids. These data are shown in Table 1. The amount of calcium required to obtain the desired saturation in each colloid was calculated from the titration curves shown in Fig. 1. Calcium was added to each electrodialized colloid in amounts equivalent to 0, 33.3, 66.6, 100.0, and 200.0 % saturation. The calcium was added as powdered $Ca(OH)_2$ to the colloids after which the suspensions were kept in glass-stoppered bottles for a period of 15 weeks for equilibrium to be established. These suspensions were shaken frequently during this period. The fixation of PO_4 at each of these degrees of calcium saturation was studied. The kinds of phosphates used are shown in Table 3.

TABLE 1.—*Chemical composition and acidity data of the colloids.*

Properties	Types of colloid			
	Lufkin	Eutaw	Oktibbeha	Cecil
$SiO_2/Fe_2O_3+Al_2O_3$	3.81	2.31	1.83	1.57
SiO_2, %	54.15	45.65	39.62	34.35
Al_2O_3, %	18.72	27.85	29.88	29.13
Fe_2O_3, %	8.49	8.96	10.86	12.55
P_2O_5, %	0.047	0.066	0.07	0.109
TiO_2, %	0.59	0.83	1.33	0.62
Total base exchange capacity*	53.0	53.2	28.8	13.0
pK of colloidal acid	5.70	5.15	6.05	6.45
Exchange capacity/pK	9.3	10.3	4.7	2.0
Dissociation, %	16.1	15.1	7.2	6.1

*Milligram equivalents per 100 grams of colloid.

METHODS OF STUDYING THE FIXATION OF THE PHOSPHATES

It was planned to use the Neubauer seedling method (17) for determining the availability of the phosphates, but preliminary tests indicated that it would not be the most suitable method. The amount of PO_4 absorbed by the rye seedlings was not proportional to the amount of soluble PO_4 added to the sand-colloidal medium when the calcium saturation varied. This was especially true with colloids saturated with hydrogen because, under that condition, an insufficient amount of calcium would be supplied to the plants. The roots of the seedlings were much better developed in the colloids of higher calcium saturation than in the more acid colloids, thus promoting a greater root contact with colloid and increasing the PO_4 absorption. Therefore, an adaption of the method of Truog (28) was used in this investigation.

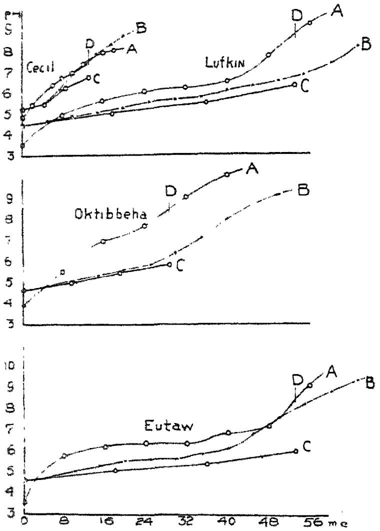

FIG. 1.—Titration curves of colloids. A=0.1 N NaOH immediately after electrodialysis. B = 0.032 N $Ca(OH)_2$, 8 months after electrodialysis. C = Precipitated $Ca(OH)_2$ 8 months after electrodialysis, added to obtain O, 33.3, 66.6, and 100% saturations. D = Point taken as saturation capacity.

A study was made (5) of the Truog method for measuring the available phosphorus. The relationship between the yields of crop in the greenhouse and the amounts of readily available PO_4 in soils was found in the case of 75 soils to have a high degree of correlation (ρ = 0.7 to 0.9). It was believed that more information on the nature of the fixation would be obtained if two concentrations, 0.05 N and 0.1 N, of H_2SO_4 were used than would be secured by Truog's method. Three grams of $(NH_4)_2SO_4$ per liter were added to the acds according to Truog's method of buffering the solution.

Preliminary tests using the two acid concentrations established the rate at which the phosphates should be added to the colloids in order to determine the amounts of PO_4 that would be suitable for measuring the fixation capacities of the colloids. These rates were found to be equivalent to 13,000 pounds of 16% superphosphate per acre on a soil containing 60% colloid for the 0.05 N acid and 2,000 pounds per acre for the 0.1 N acid. These amounts of phosphates are equivalent to 232.0 and 35.6 p. p. m. PO_4, respectively, on a dry basis of the colloid, or 7.32 and 0.11 m. e. PO_4 per 100 grams of colloid, respectively.

The various samples of colloids were set up in series in 250-cc stoppered flasks. Each flask contained 2 grams of colloids in a 3.75%

suspension and at this concentration received the different forms of phosphates. The phosphates were in contact with the colloid 24 hours during which time each series of colloids was shaken frequently and then each colloid in the various series was tested for the amount of fixation and percentage recovery of the added phosphate. It was found that there was practically no difference in the amount of PO_4 fixed at the end of 1 hour and the amount fixed at the end of a 20-day period in the case of the soluble phosphates. This is in agreement with Roszmann's results (21) that the reaction between a soluble phosphate and colloidal clay is practically instantaneous.

RESULTS

NATIVE PHOSPHORUS IN THE COLLOIDS

Table 2 shows the total PO_4 in the colloids, the soluble PO_4, and the percentage of the total native PO_4 recovered in buffered 0.05 N and 0.1 N solutions of H_2SO_4 as affected by the composition of the colloids and the degree of calcium saturation. These data show that the solubility of the native phosphorus varied with the silica-sesquioxide ratio. This relationship was more pronounced with the stronger acid solution. In other words, it may be said that the native phosphorus of the red soils had a lower availability than that of the gray soils per unit of colloid and that the greater the degree of weathering in a subtropical climate, the less the solubility of the native phosphorus.

There was little difference in the solubility of the phosphorus between the hydrogen-saturated and calcium-saturated colloids. The most soluble PO_4 was found in the colloids supersaturated with calcium hydroxide. It is doubtful if a normal soil ever approaches zero calcium saturation. When these results are applied to field conditions, no great difference might be expected in the availability of the native phosphorus in a soil with reactions between the limits of natural acidity and neutrality. However, Wityn (29), in a study of the utilization of phosphorus in soils, reported greater quantities of soluble phosphorus in acid soils than in neutral soils. He found that the availability of the soil phosphorus to plants was increased when strongly acid soils were limed. Parker and Tidmore (18) found more phosphorus in the soil solution where lime had been used. Fudge (7) found that physiologically basic fertilizers increased the phosphate availability.

PHOSPHATES ADDED TO THE COLLOIDS

Starkey and Gordon (23) showed that ferric hydroxide gels absorbed more PO_4 at low H-ion concentrations than at high concentrations. The data obtained by Mattson (14) in his study of the amphoteric behavior of soil colloids indicate that more PO_4 is absorbed at the higher H-ion concentrations than at the lower concentrations. The present study gives further practical aspects of the phosphate fixation problem. Table 3 shows the amount of PO_4 recovered from the colloids with a buffered 0.05 N solution of H_2SO_4 at the different degrees of calcium saturation when different phos-

TABLE 2.—*The soluble PO_4 and the percentage of the native PO_4 recovered from colloids buffered with 0.05 N and 0.1 N H_2SO_4 as influenced by the silica-sesquioxide ratio and the percentage of calcium saturation.*

SiO_2/R_2O_3	Total PO_4 per acre, lbs.	Calcium saturation, %	PO_4 soluble in 0.05 N H_2SO_4, p.p.m.	PO_4 recovered in 0.05 N H_2SO_4, %	PO_4 soluble in 0.1N H_2SO_4, p.p.m.	PO_4 recovered in 0.1 N H_2SO_4, %
			Lufkin Colloid			
3.81	634	0.0	6.8	2.14	12.8	4.04
		33.3	6.4	2.02	12.6	3.98
		66.6	6.4	2.02	12.4	3.91
		100.0	6.5	2.02	12.0	3.78
		200.0	5.2	1.61	31.2	9.85
		200.0	6.8*	2.14	—	—
			Eutaw Colloid			
2.31	882	0.0	4.4	0.99	10.4	2.35
		33.3	4.4	0.99	9.6	2.17
		66.6	4.8	1.09	9.4	2.13
		100.0	5.2	1,18	9.4	2.13
		200.0	10.4	2.35	30.8	6.98
		200.0	12.2*	2.74	—	—
			Oktibbeha Colloid			
1.83	1,037	0.0	4.4	0.85	3.6	0.69
		33.3	4.4	0.85	3.6	0.69
		66.6	4.8	0.92	3.6	0.69
		100.0	6.0	1.15	3.6	0.69
		200.0	8.2	1.58	11.6	2.23
		200.0	7.7*	1.48	—	—
			Cecil Colloid			
1.57	1.456	0.0	3.2	0.44	3.6	0.49
		33.3	2.8	0.38	4.4	0.60
		66.6	2.8	0.38	4.4	0.60
		100.0	2.8	0.38	4.8	0.60
		200.0	3.6	0.49	8.0	0.66
		200.0	5.2*	0.71	—	—

*0.1 N H_2SO_4 was added to the 0.05 N H_2SO_4 in an amount equivalent to the calcium above saturation.

phates had been added. The pH values of the colloids before and after the addition of the phosphates and in the buffered acid solution in contact with the phosphated colloid are also given. These results are discussed with the data presented in Table 4, which shows the amount of PO_4 recovered when the buffered 0.1 N H_2SO_4 was used.

DISCUSSION

THE REACTION OF THE COLLOIDS

The pH values were obtained only from the colloid systems treated with the 0.05 N acid. The pH values of the colloids at various degrees of calcium saturation have been plotted in Fig. 1, curve C. The buffer action of the colloids prevented great changes in the pH values with the changes in the percentage of calcium saturation. The pH values of the colloids, when saturated with hydrogen, taken immediately after electrodialysis were nearly 1.0 pH lower for each colloid than those taken after the colloids stood 8 months, thus indicating that the hydrogen colloid became less dissociated as true equilibrium was established. The magnitude of this change in the pH values varied directly with the total base exchange capacity of the colloid. The $Ca(OH)_2$ added to the colloid as a powder did not neutralize the same amount of hydrogen as an equivalent amount of $Ca(OH)_2$ added in a 0.032 N solution. This is apparent by comparing curves B and C in Fig. 1.

The changes in the pH values resulting from the addition of the various phosphates do not seem to be related to any of the properties of the colloids used; however, the different forms of phosphates exhibited certain general tendencies as shown by the data in Table 3. Ortho-phosphoric acid tended to increase the H-ion concentration in the low-calcium-saturated colloids, except for the Eutaw colloid. Mono-calcium phosphate increased the pH value of the Lufkin colloid and decreased it in the case of the Eutaw and Cecil colloids. Di-calcium phosphate, tri-calcium phosphate, and rock phosphate did not influence the pH values, while tri-basic sodium phosphate decreased the H-ion concentration as much as 0.6 of a pH.

FIXATION OF THE VARIOUS FORMS OF PHOSPHATES

The data in Table 4 show that the phosphate-fixation capacity of the colloids, as determined with the 0.1 N H_2SO_4, is inversely proportional to the silica-sesquioxide ratio. These results are in accord with those reported by Mattson (14). This relationship does not appear to hold where the 0.05 N acid was used in the case of the Lufkin colloid as indicated by the data in Table 3. The amount of PO_4 recovered from the Lufkin colloid with the 0.05 N acid was lower than would be expected in view of the results obtained with the 0.1 N acid. This behavior of the Lufkin colloid with the dilute acid is explained by the important results of Comber (4). He found that, when a soil was treated with a dilute acid, phosphates came into solution rapidly and iron and aluminum slowly, causing at first a high phosphate concentration which was soon lowered by the precipitation of ferric and aluminum phosphates. When the concentration of the acid was increased, the ferric and aluminum phosphates were brought back into solution.

In the authors' work with the 0.05 N acid, the first condition described by Comber probably existed and when the 0.1 N acid was used the iron and aluminum phosphates were brought into solution. The data presented by Teakle (25) further substantiate these results. The pH values of the unsaturated, phosphated Lufkin colloids in contact with the buffered 0.05 N acid were 3.0 to 3.3, thus corresponding to the conditions where the iron phosphate would be least soluble. It was also found that at the end of 1 hour more PO_4 was in solution in the phosphated colloidal suspension of the Lufkin in contact with the 0.05 N acid than at the end of 16 hours. Both concentrations of acid were in contact with the phosphated colloids for 16

TABLE 3.—*The pH values and the PO_4 recovered*

Forms of phosphates added to colloids	Calcium saturation, %	Type of colloid and silica-sesquioxide ratio									
		Lufkin, 3.81					Eutaw, 2.31				
		pH before addition of phosphates	pH after addition of phosphates	pH with N/500 H_2SO_4	Soluble PO_4† (dry colloid) p.p.m.	Recovery of added phosphates %	pH before addition of phosphates	pH after addition of phosphate	pH with N/500 H_2SO_4	Soluble PO_4 (dry colloid) p.p.m.	Recovery of added phosphates %
H_3PO_4	0	4.43	4.25	3.06	41.2	14.8	4.55	5.10	3.10	150.2	62.8
	33.3	4.90	4.70	3.17	58.0	22.2	5.05	5.46	3.17	144.5	60.3
	66.6	5.35	5.24	3.32	61.2	23.6	5.40	5.69	3.27	129.7	53.7
	100.0	6.10	5.95	3.49	65.2	25.3	5.95	5.78	3.40	119.4	49.3
	200.0	7.20	7.70	5.12	18.0	5.5	8.80	8.85	6.28	22.8	5.3
	200.0	—	—	3.45*	14.4	3.3	—	—	3.65*	54.0	17.7
Monocalcium phosphate	0	4.43	4.25	3.07	38.0	13.4	4.55	5.20	3.10	125.4	52.2
	33.3	4.90	4.70	3.18	58.0	22.2	5.05	5.45	3.20	125.4	52.2
	66.6	5.35	5.24	3.32	58.0	22.2	5.40	5.65	3.26	121.4	50.2
	100.0	6.10	5.90	3.51	58.0	22.2	5.95	5.80	3.46	96.2	39.2
	200.0	7.20	7.32	5.20	17.2	5.2	8.80	8.83	6.36	18.8	3.6
	200.0	—	—	3.45*	13.2	2.7	—	—	3.63*	54.0	17.7
Dicalcium phosphate	0	4.43	4.33	3.07	43.6	15.8	4.55	5.29	3.11	156.4	65.5
	33.3	4.90	4.85	3.16	80.6	31.9	5.05	5.58	3.22	144.5	60.5
	66.6	5.35	5.23	3.33	79.7	31.6	5.40	5.74	3.30	141.8	59.1
	100.0	6.10	6.00	3.50	113.6	46.2	5.95	5.82	3.47	129.8	53.6
	200.0	7.20	7.26	5.24	16.4	4.8	8.80	8.57	6.55	14.8	1.9
	200.0	—	—	3.45*	18.2	4.8	—	—	3.65*	67.6	23.6
Tricalcium phosphate	0	4.43	4.31	3.08	50.8	18.9	4.55	5.15	3.12	109.0	45.1
	33.3	4.90	4.78	3.20	44.4	16.4	5.05	5.40	3.22	103.0	42.5
	66.6	5.35	5.23	3.35	70.0	27.4	5.40	5.63	3.30	101.6	41.7
	100.0	6.10	5.97	3.50	70.0	27.4	5.95	5.80	3.47	88.3	35.8
	200.0	7.20	7.28	5.30	15.6	4.5	8.80	8.43	6.43	14.8	1.9
	200.0	—	—	3.48*	14.4	3.3	—	—	3.64*	54.0	17.7
Rock phosphate (pass thru 0.1-mm mesh)	0	4.43	4.38	3.08	22.0	6.5	4.55	4.67	3.08	70.8	28.6
	33.3	4.90	4.73	3.18	63.6	24.6	5.05	5.09	3.18	70.6	28.5
	66.6	5.35	5.20	3.32	63.6	24.6	5.40	5.54	3.29	59.6	23.6
	100.0	6.10	5.97	3.48	36.4	12.9	5.95	5.74	3.46	38.0	14.1
	200.0	7.20	7.33	5.25	—	4.5	8.80	8.50	6.06	9.4	−0.4
	200.0	—	—	3.45*	10.6	1.6	—	—	3.52*	26.0	5.6
Sodium phosphate (tribasic)	0	4.43	4.74	3.09	43.6	15.8	4.55	5.48	3.18	150.2	62.8
	33.3	4.90	5.10	3.18	76.4	30.2	5.05	5.67	3.23	150.2	62.8
	66.6	5.35	5.40	3.34	76.4	30.2	5.40	5.86	3.31	141.8	59.1
	100.0	6.10	6.10	3.50	76.4	30.2	5.95	5.95	3.47	87.3	35.4
	200.0	7.20	7.33	5.28	18.0	5.5	8.80	8.80	6.55	18.3	3.4
	200.0	—	—	3.48*	14.4	3.3	—	—	3.65*	52.4	17.0

*Sufficient N/10 H_2SO_4 was added to the N/500 H_2SO_4 to account for the calcium present

†The various phopshates were added to the colloids at a rate equivalent to 13,000 pounds

from soil colloids with buffered 0.05 N H_2SO_4.

Type colloid and silica-sesquioxide ratio									
Oktibbeha, 1.83					Cecil, 1.57				
pH before addition of phosphates	pH after addition of phosphates	pH with N/500 H_2SO_4	Soluble PO_4† (dry colloid) p.p.m.	Recovery of added phosphates %	pH before addition of phosphates	pH after addition of phosphates	pH with N/500 H_2SO_4	Soluble PO_4 (dry colloid) p.p.m.	Recovery of added phosphates %
4.60	4.45	3.10	123.3	51.2	5.16	5.07	3.22	69.2	28.4
4.95	4.84	3.17	123.3	51.2	5.44	5.37	3.25	68.4	28.3
5.40	5.30	3.22	123.3	51.0	6.15	6.01	3.30	66.4	27.4
5.80	5.52	3.30	111.3	45.4	6.65	6.75	3.39	63.6	26.2
7.20	7.44	4.05	48.4	17.4	7.65	7.63	3.83	42.0	16.5
—	—	3.25*	54.8	20.3	—	—	3.42*	46.8	17.9
4.60	4.55	3.10	105.9	43.7	5.16	5.37	3.25	58.8	24.0
4.95	4.85	3.18	107.5	44.4	5.44	5.47	3.27	58.0	23.4
5.40	5.36	3.22	107.5	44.2	6.15	6.30	3.38	56.4	23.1
5.80	5.63	3.30	103.0	41.8	6.65	6.90	3.38	52.4	21.4
7.20	7.23	4.08	46.8	16.7	7.63	7.46	3.80	39.6	15.5
—	—	3.26*	41.2	14.5	—	—	3.42*	38.0	14.2
4.60	4.67	3.11	127.5	53.0	5.16	5.44	3.25	95.1	39.6
4.95	4.85	3.20	132.0	55.0	5.44	5.46	3.28	95.1	39.7
5.40	5.33	3.24	144.5	60.2	6.15	6.18	3.31	95.1	39.7
5.80	5.57	3.35	129.7	53.3	6.65	6.81	3.38	91.0	38.0
7.20	7.35	4.10	60.4	22.6	7.63	7.30	3.82	56.0	22.6
—	—	3.28*	62.8	23.8	—	—	3.42*	64.4	25.5
4.60	4.72	3.13	97.6	40.2	5.16	5.31	3.26	60.4	24.6
4.95	4.95	3.20	97.6	40.2	5.44	5.55	3.29	60.4	24.8
5.40	5.52	3.23	97.6	40.0	6.15	6.25	3.31	60.4	24.8
5.80	5.71	3.31	109.0	44.4	6.65	6.90	3.38	59.6	24.5
7.20	7.20	4.09	34.0	11.2	7.63	7.35	3.82	39.6	15.5
—	—	3.25*	67.2	25.7	—	—	3.42*	53.2	20.7
4.60	4.67	3.12	110.6	45.8	5.16	5.18	3.26	66.0	27.0
4.95	4.85	3.18	96.4	39.7	5.44	5.58	3.29	66.0	27.3
5.40	5.35	3.23	85.2	34.6	6.15	6.55	3.30	63.6	26.2
5.80	5.58	3.32	80.6	32.1	6.65	6.81	3.37	55.6	22.8
7.20	7.23	4.10	36.4	12.1	7.63	7.29	3.80	23.6	8.6
—	—	3.26*	73.2	28.3	—	—	3.43*	54.8	21.4
4.60	5.20	3.12	141.8	59.3	5.16	5.77	3.28	88.8	36.8
4.95	5.16	3.17	136.7	57.1	5.44	6.04	3.30	88.8	37.0
5.40	5.67	3.25	129.7	53.7	6.15	6.75	3.35	89.9	37.5
5.80	6.00	3.32	123.3	50.6	6.65	6.83	3.41	89.9	37.5
7.20	7.10	4.08	60.4	21.6	7.65	7.76	3.82	48.4	19.4
—	—	3.27*	54.8	20.3	—	—	3.44*	57.4	22.4

in an amount twice the quantity of that used in order to obtain the 100% saturation. of 16% superphosphate per acre to a soil with a 60% colloid content.

hours in the regular procedure for determining the extent of PO_4 fixation. The question then arises, Why is the phosphate brought into solution by the 0.05 N acid in the Cecil, Oktibbeha, and Eutaw colloids not also precipitated by iron and aluminum? When the differences with respect to extent of weathering of the four types of colloids are considered, the answer seems evident. The Lufkin colloid is highly unweathered and poorly aerated; the other colloids are weathered and aerated to greater degrees. Easily soluble components would have been already removed or made less soluble by oxidation and dehydration where the weathering had progressed to an appreciable extent. The absence of extensive weathering activities on the Lufkin colloids probably leaves the iron and aluminum in a relatively soluble condition and, therefore, these two elements may be brought into solution by the dilute acid in spite of the fact that the total content of iron and aluminum is lower than in the other colloids. Without doubt, some iron and aluminum came into solution and precipitated varying amounts of phosphorus in the Eutaw, Oktibbeha, and Cecil colloids, but the amounts of phosphorus precipitated were much less than in the Lufkin colloid.

The precipitation of added soluble phosphates as iron and aluminum phosphates in a dilute acid-extracting solution is probably the chief reason why results on some soils do not fit accurately into the correlation between the phosphorus obtained by acid-extracting methods and the yield of crops. When it is recalled that absorption by plant roots is a continuous process and that, as Truog (27) points out, the root-soil contact is a separate system from that of the soil solution, it seems probable that the phosphate ion is removed by the plant as soon as formed by the solvent action of H_2CO_3 and that little or no precipitation with iron and aluminum is likely to occur. It is believed, therefore, that the amount of the PO_4 recovered with the 0.05 N acid from the Lufkin colloid does not represent the amount which may be recovered by plants. When the data from the Lufkin colloid in Table 3 are excluded, it seems reasonable to believe that the data for the Eutaw, Oktibbeha, and Cecil colloids represent closely the actual fixation of the PO_4 ions into forms unavailable to plants. The data also show how the fixation is influenced by the forms of phosphates, by the composition of the colloid, and by the degree of calcium saturation of the colloid.

Truog's method for measuring the readily available phosphorus in soils does not provide for any change in the concentration of the acid used when soils are tested that have sufficient bases present to neturalize some of the acid of the extracting solution. It will be noted in Table 3 that an excess of acid was used for each colloid that contained an amount of calcium equivalent to 200% saturation. The amount of the excess acid used was equivalent to the amount of calcium in the colloid above saturation. In all the cases the pH values were similar to those for the 100% saturated colloid. It will be noted that the increased acidity increased the quantity of PO_4 recovered in all the colloids except the Lufkin. The reason for this exception has been explained according to Comber's and Teakle's results.

Phosphates added to colloids*	Calcium saturation, %	Type of colloid and silica-sesquioxide ratio							
		Lufkin, 3.81		Eutaw, 2.31		Oktibbeha, 1.83		Cecil, 1.57	
		Soluble PO_4, p.p.m.	Recovery of added phosphate, %	Soluble, PO_4, p.p.m.	Recovery of added phosphate, %	Soluble PO_4, p.p.m.	Recovery of added phosphate, %	Soluble PO_4, p.p.m.	Recovery of added phosphate, %
H_3PO_4	0	54.8	117.7	40.4	84.0	27.6	67.3	14.8	31.4
	33.3	53.2	113.8	40.4	86.3	28.4	69.5	14.8	29.4
	66.6	51.6	109.9	39.6	84.7	29.2	71.8	14.0	29.7
	100.0	48.4	102.0	36.2	75.1	28.4	69.5	14.0	25.8
	200.0	78.4	132.3	58.4	77.4	36.2	69.0	23.2	42.6
Mono-calcium phosphate	0	53.6	114.4	36.2	72.3	26.0	62.8	10.8	20.2
	33.3	49.6	103.7	34.8	70.6	26.0	62.8	11.6	20.2
	66.6	48.6	104.2	34.0	69.0	26.0	62.8	11.6	20.2
	100.0	46.8	97.6	32.4	64.5	26.0	62.8	12.8	22.4
	200.0	66.8	92.8	54.8	67.2	32.8	60.5	16.0	22.4
Di-calcium phosphate	0	55.8	120.5	36.2	72.3	25.2	60.5	11.6	22.4
	33.3	47.2	97.0	34.8	70.6	19.6	44.9	14.4	28.0
	66.6	44.6	90.3	34.0	69.0	18.4	41.5	14.8	29.2
	100.0	44.6	91.4	32.4	64.5	12.4	28.7	17.2	34.7
	200.0	66.8	99.8	54.8	67.2	29.0	48.8	25.6	49.3
Tri-calcium phosphate	0	44.6	89.0	31.2	58.3	13.6	28.0	8.8	14.6
	33.3	44.4	89.1	29.6	58.1	13.2	26.9	9.2	13.5
	66.6	40.8	79.6	29.2	55.5	12.8	25.8	9.2	13.5
	100.0	40.4	79.6	28.4	53.3	12.4	27.5	13.0	23.0
	200.0	55.6	68.4	50.4	54.9	26.4	41.5	22.0	39.2
Rock phosphate (pass thru 0.1-mm mesh)	0	35.2	62.8	30.4	56.1	14.0	29.1	8.8	14.6
	33.3	36.0	65.6	30.8	59.4	13.2	26.9	10.0	15.7
	66.6	36.0	66.2	30.8	57.2	13.2	26.9	11.6	20.2
	100.0	34.8	63.9	29.2	55.5	15.2	32.5	12.8	23.5
	200.0	32.4	3.4	48.4	49.3	22.8	31.4	22.0	39.2
Sodium phosphate (tribasic)	0	47.6	97.6	42.0	88.6	17.6	39.2	12.8	25.8
	33.3	47.6	98.1	42.0	90.8	17.6	39.2	12.8	23.5
	66.6	48.4	100.0	42.0	88.6	17.6	39.2	12.8	23.5
	100.0	49.2	104.2	43.2	94.7	18.0	40.4	16.6	33.1
	200.0	67.2	100.9	65.6	97.6	28.4	47.1	26.0	50.5

The solvent action of H_2CO_3 excreted by plant roots is well known. Carbonic acid is weak and, even though the root-soil contact is a system quite different from the soil solution, it seems probable that some H_2CO_3 would be neutralized when excreted into a soil containing an excess of $CaCO_3$ to form $Ca(HCO_3)_2$, thus less acid would remain to exert its solvent action. The investigations by Davis and Scarseth (5) with the Truog method included several calcareous clay soils and the low content of readily available PO_4 obtained from these soils had a high correlation with the plant yields ($\rho = 0.88$). In the case of the calcium-supersaturated colloids, it is believed that the amount of PO_4 extracted by 0.05 N acid rather than that extracted by 0.1 N acid represents more nearly the amount of PO_4 available to plants. With Truog's method, the acidity of the extracting acid is decreased by the excess of calcium in the supersaturated colloids used and less phosphate is brought into solution. The fact that the extracting acid is neutralized in alkaline soils may be the reason that Truog's method gave results which could be correlated with the plant performance in the calcareous soils mentioned.

It will be noted in Table 3, excluding the Lufkin colloid, that orthophosphoric acid, di-calcium phosphate, and sodium phosphate were about equal in availability and were more available than the other forms of phosphates in the gray colloids, i. e., the colloids high in silica and low in sesquioxides; but the sodium and di-calcium phosphates were more available than the phosphoric acid in the red colloids. Mono-calcium phosphate was fixed slightly more than the di-calcium phosphate in all the colloids. It should be recalled that mono-calcium phosphate is more soluble than the di-calcium phosphate and less acid than the phosphoric acid. Tri-calcium phosphate was about 10% less available than the mono-calcium phosphate in the gray colloid and about equal to it in the red colloid. The rock phosphate was approximately 20% less available than mono-calcium phosphate in the gray colloid and slightly more available than the mono-calcium phosphate in the red colloid. These results do not agree entirely with some data by Thornton (26) who compared the relative availabilities of many forms of phosphates in a sand and in a soil using the Neubauer method. However, the results which Thornton obtained with a soil where KCl was added are in fair agreement with the relative values for the various phosphates reported in this paper.

EFFECT OF CALCIUM SATURATION

It should be remembered that $Ca(OH)_2$ was used to obtain the various degrees of calcium saturation and that the OH- and CO_3-ions may influence the phosphate absorption differently, especially in the supersaturated colloids. The effect of various calcium saturations on the fixation of PO_4 from the different phosphates may be seen in Table 3. The Lufkin colloid shows a minimum phosphate fixation between 66.6 and 100.0% calcium saturation. The large amount of absorption of the phosphate by the colloid of 0 calcium saturation may be explained by the probable increase of iron and aluminum in the solution with the phosphates at the pH value of about 4.3, which precipitated some of the soluble phosphate ions. It is not so easy to explain the low phosphate solubility in the colloid containing calcium equivalent to 200% calcium saturation. It is interesting to note, however, that the extracting acid, in contact with this colloid at the pH value of 5.2, recovered more PO_4 than when the extracting acid was strengthened to maintain a pH value of about 3.4. This behavior was reversed with the other colloids. Evidently more data are necessary before this phenomenon can be explained.

With the Eutaw, Oktibbeha, and Cecil colloids there was a general tendency for more PO_4 to be recovered in the colloids of lower calcium saturation. However, the greater the silica-sesquioxide ratio of the colloids from these three soils, the larger was the amount of PO_4 recovered by the 0.05 N acid in the 200% calcium saturated colloids. On the other hand, the greater the sesquioxide content of these colloids, the smaller was the amount of PO_4 recovered from the more unsaturated calcium colloids.

It is interesting to note that supersaturating the colloids with calcium decreased the availability of the applied phosphate, but the native phosphorus was found to be made more available when the colloid was supersaturated with calcium. It has been stated that less PO_4 was recovered from the calcium supersaturated gray colloids than from the supersaturated red colloids. The pH values of the acid-extracting solution in contact with the phosphated colloids show that there were less H ions present with the gray colloids than with the red colloids. The greater the silica-sesquioxide ratio of the colloid the greater was the base exchange capacity and likewise the greater was the quantity of $Ca(OH)_2$ necessary to obtain the 200% saturated colloid. Therefore, the greater the amount of calcium used the greater would be the neutralizing effect on the extracting acid. The pH of the 200% saturated colloid in contact with the 0.05 N acid was about 6.3 in the Lufkin colloid, whereas it was only about 3.8 in the corresponding degree of saturation for the Cecil colloid.

It will be noted in Table 4 that there was some negative PO_4 absorption where the most acid forms of phosphates were added and 0.1 N H_2SO_4 was used as the extracting acid.

SUMMARY

The results may be briefly summarized as follows:

1. The amount of available phosphate in soil colloids varied directly with the silica-sesquioxide ratio of the colloid.
2. The native phosphate in soil colloids was about as soluble in hydrogen-saturated as in calcium-saturated colloids, but it was most soluble in the colloids supersaturated with calcium.
3. The phosphate-fixing capacity of soil colloids varied inversely with the silica-sesquioxide ratio of the colloid.
4. In the least weathered colloid the concentration of phosphate ions brought into solution by 0.05 N H_2SO_4 at pH 3.0 was considerably decreased on standing for a period of 16 hours. The concentration of phosphate ions was not decreased on standing 16 hours in contact with a 0.1 N H_2SO_4 solution.

5. Fixation of the phosphate from ortho-phosphoric acid, di-calcium phosphate, and tri-basic sodium phosphate was about equal in the colloids with a high silica-sesquioxide ratio when the degree of calcium saturation was below 100%. Di-calcium and sodium phosphates were slightly more available than the ortho-phosphoric acid in the colloids with the low silica-sesquioxide ratios. Mono-calcium phosphate was fixed slightly more than di-calcium phosphate in all the colloids. Tri-calcium phosphate was about 10% less available than mono-calcium phosphate in the gray colloids and about equal to it in the red colloids. The rock phosphate was approximately 20% less available than mono-calcium phosphate in the gray colloids and was slightly more available than mono-calcium phosphate in the red colloids.

6. At pH 5.4, about 76% of the PO_4 added as mono-calcium phosphate to the red colloid was insoluble in buffered 0.05 N H_2SO_4; the phosphate application was equivalent to 13,000 pounds of 16% superphosphate per acre to a soil containing 60% colloids.

7. The lower the silica-sesquioxide ratio the smaller was the influence of the degree of calcium saturation below 100% on the amount of phosphate fixed by the colloid. On the other hand, the tendency was for more phosphate to be soluble when the colloids contained calcium equivalent to 200% saturation.

LITERATURE CITED

1. AUSTIN, R. H. Some reactions between mono-calcium phosphate and soils. Soil Science, 24:263–269. 1927.
2. BAVER, L. D., and SCARSETH, G. D. Subtropical weathering in Alabama as evidenced in the Susquehanna fine sandy loam profile. Soil Res., 2:288–307. 1931.
3. BREAZEALE, J. F., and BURGESS, P. S. The availability of phosphates in calcareous or alkaline soils. Ariz. Agr. Exp. Sta. Tech. Bul. 10. 1926.
4. COMBER, N. M. The rôle of electronegative ions in the reactions between soils and electrolytes. Trans. Faraday Soc., 20:567–572. 1925.
5. DAVIS, F. L., and SCARSETH, G. D. Some correlations between crop yields and the readily available phosphorus in soils as determined by Truog's method. Jour. Amer. Soc. Agron., 24:909–920. 1932.
6. FORD, M. C. The distribution, availability, and nature of the phosphates in certain Kentucky soils. Jour. Amer. Soc. Agron., 24:395–410. 1932.
7. FUDGE, J. F. Influence of various nitrogenous fertilizers on availability of phosphate. Jour. Amer. Soc. Agron., 20:280–293. 1928.
8. GEMMERLING, V. V. The absorption of phosphoric acid by soils. Trudy Nauch. Inst. Udobr., Trans. Soil Inst. Fert., Moscow, 34:46–50. 1926.
9. HARRISON, W. H., and DAS, SURENDRALAL. The retention of soluble phosphates in calcareous and non-calcareous soils. Mem. Dept. Agr., India, 9:195–236. 1921.
10. INGHAM, G. The relative availability of phosphatic fertilizers on acid and non-acid soils. S. Afr. Jour. Sci., 22:122–134. 1925.
11. KAPPEN, H. The action of superphosphate on acid soils. Deut. Landw. Presse, 52, 41:484–485; 42:496–497. 1925.

KARRAKER, P. E. The delayed effect of liming. Soil Science, 24:147–148. 1927

MATTSON, S. The relation between the electrokinetic behavior and the base exchange capacity of soil colloids. Jour. Amer. Soc. Agron., 18:458–470. 1926.

—————. Anionic and cationic absorption by soil colloidal materials of varying $SiO_2/Al_2O_3 + Fe_2O_3$ ratio. Proc. First Intern. Cong. Soil Sci., Comm. II, 2:199–211. 1927.

15. ———————. The laws of colloidal behavior: VI. Amphoteric behavior. Soil Science, 32:343–365. 1931.
16. MIDGLEY, A. R. The movement and fixation of phosphates in relation to permanent pasture fertilization. Jour. Amer. Soc. Agron., 23:788–799. 1931.
17. NEUBAUER, H., and SCHNEIDER, W. Nahrstoffaufnahme der Keimpflanzen und ihre Anwendung auf die Bestimmung des Nahrstoffgehalts der Boden. Ztschr. Pflanzen Ehnahr. u. Dungung., 2 (a):329–362. 1923.
18. PARKER, F. W., and TIDMORE, J. W. Influence of lime and phosphatic fertilizers on the phosphorus content of the soil solution and soil extracts. Soil Science, 21:425–441. 1926.
19. PIERRE, W. H., and PARKER, F. W. The concentration of organic and inorganic phosphorus in the soil solution and the availability of organic phosphorus to plants. Soil Science, 24:119–128. 1927.
20. ROBERTS, GEORGE. Effect of associated soil treatments on the availability of applied phosphates to field crops on different soil types. Jour. Amer. Soc. Agron., 22:489–497. 1930.
21. ROSZMANN, C. A. Retention of phosphorus by soil colloids. Soil Science, 24:465–474. 1927.
22. SCARSETH, G. D. Morphological, greenhouse, and chemical studies of the Black Belt soils of Alabama. Ala. Agr. Exp. Sta. Bul. 237. 1932.
23. STARKEY, E. B., and GORDON, N. E. The influence of hydrogen-ion concentration on the absorption of plant food by soil colloids Soil Science, 14: 449–457. 1922.
24. STEVENSON, R. E., and CHAPMAN, H. D. Phosphate penetration in field soils. Jour. Amer. Soc. Agron., 23:759–770. 1931.
25. TEAKLE, L. J. H. Phosphate in the soil solution as affected by reaction and cation concentration. Soil Science, 25:143–162. 1928.
26. THORNTON, S. F. Factors affecting the availability of phosphate fertilizers as shown by the Neubauer method. Jour. Assoc. Off. Agr. Chem., 15: 163–166. 1932.
27. TRUOG, E. How plants feed. Proc. First Intern. Cong. Soil Sci., Comm. IV, 3:628–636. 1927.
28. TRUOG, E. The determination of the readily available phosphorus in soils. Jour. Amer. Soc. Agron., 22:874–883. 1930.
29. WITYN, J. Better utilization of soil phosphoric acid. Ztschr. Pflanzen Ehnahr u. Dungung, 6:27–51. 1925.
30. WOLKOFF, M. I. Relative availability of the phosphorus of raw rock and acid phosphate in soil. Soil Science, 17:39–56. 1924.

THE FIXATION OF PHOSPHATES BY CLAY SOILS[1]

G. D. SCARSETH and J. W. TIDMORE[2]

During the past 3 years greenhouse pot experiments have been conducted on heavy clay soils from the Black Belt of Alabama and the results have been reported (4)[3]. Nearly all of the soils studied showed a marked deficiency of available phosphorus and produced satisfactory crop yields only when very heavy applications of phosphatic fertilizers were made. The soils in this area differ greatly in reaction, varying from very acid to alkaline. Some of the latter soils have a very high $CaCO_3$ content. Preliminary experiments showed that phosphates were rapidly made unavailable to plants. In order to learn more about the phosphate fixing properties of the soils in this area, two greenhouse experiments were conducted and the results are herein reported.

The objects of these experiments were to study (a) the degree and rate of fixation of different phosphates in a highly colloidal, acid clay soil; (b) the influence of $CaCO_3$ on the phosphate fixation in the acid soil; and (c) the degree and rate of fixation of superphosphate in a highly colloidal clay soil having a high $CaCO_3$ content.

EXPERIMENTAL

The Vaiden and Sumter clays from the Black Belt were used to represent the acid and the calcareous soil groups, respectively. The Vaiden clay is an intermediate type between the Oktibbeha and the Eutaw clays. It has a colloidal content of about 60% (dry basis). The sample used had a pH value of 4.8 and a lime requirement, according to the method of Pierre and Worley (2), of 11,474 pounds of $CaCO_3$ per 2 million pounds of soil. The Sumter clay soils are weathered from a soft chalk. The sample used had a pH value of 7.5, a $CaCO_3$ content of 9.3%, and a total P_2O_5 content of 0.1081%.

ACID SOIL

Sufficient Vaiden clay to fill 268 2-gallon glazed pots was thoroughly mixed, potted, and placed in a greenhouse. The fertilizer treatments were made in duplicate on an unlimed and a limed series. Nitrogen and potassium were added in solution as $NaNO_3$ and KCl, respectively, to all the pots with the first watering after planting. Phosphorus was supplied as mono-calcium, di-calcium, tri-calcium, ferric (C. P., old precipitate), and mono-ammonium phosphates, and as superphosphate. Each of these phosphates was mixed into the soil at three rates equivalent in P_2O_5 content to 300, 900, and 1,800 pounds of 16% superphosphate per acre, respectively, and was applied at four intervals of time, which were 365, 180, 30, and 0 days before planting. At the same time intervals before planting lime in the form of precipitated $CaCO_3$ was applied at the rate of

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[2] Assistant Soil Chemist and Soil Chemist, respectively.

[3] Reference by number is to "Literature Cited", p. 162.

11,474 pounds per acre which was sufficient to bring the reaction to pH 6.5. Immediately after the fertilizers were applied the soil was brought up to approximately field moisture and maintained at this level until planting time. Sorghum was used as the test crop and was allowed to grow for 55 days. The yields reported are the averages from the duplicate treatments. The available phosphorus for each treatment was determined at the time of planting by Truog's (6) method. The soil sample for each analysis was obtained by compositing three cores of soil from each pot.

RESULTS

EFFECT OF VARYING THE KINDS AND RATE OF APPLICATIONS OF PHOSPHATES

The yields of sorghum and the amount of readily available PO_4 in the soil at the time of planting as influenced by the different kinds of phosphates are shown in Table 1. It should be noted that with each kind of phosphate the yields increased as the rate of application

TABLE 1.—*The available PO_4 in an unlimed Vaiden clay at the time of planting and the yield of sorghum as affected by different phosphates.**

Pot No.	Rate, equivalent to pounds of superphosphate per acre	Available PO_4 Truog's method, p.p.m.	Yield in dry weight, grams	Relative yields
		No Phosphate		
1	0	10.0	0.6	2.1
		Mono-calcium Phosphate		
3	300	30.0	10.7	38.9
51	900	145.0	14.5	52.7
99	1,800	165.0	27.5	100.0
		Di-calcium Phosphate		
5	300	48.8	9.0	32.7
53	900	136.5	24.6	89.5
101	1,800	249.2	28.5	103.5
		Tri-calcium Phosphate		
7	300	20.8	5.6	20.4
55	900	61.6	12.4	45.0
103	1,800	107.2	15.7	57.2
		Superphosphate		
9	300	37.6	8.8	32.0
57	900	143.5	17.2	62.6
105	1,800	287.3	32.2	117.1
		Ferric Phosphate		
11	300	16.0	2.6	9.4
59	900	23.2	3.7	13.5
107	1,800	27.2	6.8	24.7
		Mono-ammonium Phosphate		
13	300	46.4	9.9	36.0
61	900	70.4	20.7	75.3
109	1,800	80.1	30.2	109.9

*Phosphates applied immediately before planting sorghum.

increased. The treatments receiving no phosphorus produced almost no plant growth. The relative yields for mono-calcium, di-calcium, tri-calcium, mono-ammonium, and ferric phosphates and for superphosphate were 100, 103, 57, 110, 25, and 117, respectively, when these materials were applied at the time of planting at a rate equivalent to 1,800 pounds of superphosphate per acre. A fairly close relationship existed between the amount of readily available PO_4 in the soil at the time of planting and the yield produced. A better correlation might have been expected except for the fact that the plants were growing for 55 days and that the phosphates were being fixed during this period.

EFFECT OF VARYING TIME OF APPLICATION OF PHOSPHATES

The yields of sorghum and the amount of readily available PO_4 present at planting time as affected by the time of applying the various phosphates are given in Table 2. It will be seen in general that the available PO_4 and the yield declined rapidly as the period of time for the soil and phosphate contact increased. Nearly all the available PO_4 had been fixed at the end of the 365-day period, particularly as measured by the crop yield. The sixth column in this table shows the relative yields of sorghum obtained from the various forms of phosphates as influenced by the time of contact with the soil. It is interesting to note that in general the more insoluble the form of phosphate the slower the fixation. In the case of the calcium phosphates the more soluble forms were fixed most rapidly. Ferric phosphate was fixed at the slowest rate, although it produced very low yields.

EFFECT OF $CaCO_3$ ON AVAILABILITY OF PHOSPHATES

Many investigators have noted that liming frequently caused a decrease in the yields of crops. Karraker (1) pointed out the delayed effect of liming in some experiments with alfalfa. That the reduction in yield and the delayed effect of liming are closely associated with the phosphate ions in the soil is shown in Table 3 and Figs. 1 and 2 which show the effect of $CaCO_3$ on the availability of the different phosphates where they were applied at low and high rates. Calcium carbonate decreased the availability of the various phosphates applied at the low rates. This effect decreased as the length of time the $CaCO_3$ had been in the soil increased. With the high phosphate rates, there was a general reduction in the yields produced from liming but of less magnitude than with the low rates and, with the exception of tri-calcium phosphate, the depressing effect decreased rapidly as the length of time that the $CaCO_3$ had been in the soil increased. The yield with the high rate of tri-calcium phosphate was decreased about 60% by the $CaCO_3$ when it was applied at planting and about 97% by the $CaCO_3$ when it was applied 180 and 365 days before planting. The yields and the available PO_4 were not reduced so much by the $CaCO_3$ with the more soluble as with the less soluble phosphates. When the $CaCO_3$ had been in contact with the soil for 365 days, the high rate of mono-ammonium phosphate gave practically as great a yield with the $CaCO_3$ as without it.

TABLE 2.—*The available PO_4 in a Vaiden clay at the time of planting and the yield of sorghum as affected by various phosphates applied at different periods of time before planting.*

Pot No.	No. of days phosphate applied before planting*	Available PO_4 Truog's method, p.p.m.	Yield in dry weight, grams	Relative yields for each form	Relative yields compared to mono-calcium phosphate
		No phosphate			
1	—	10.0	0.6	—	2.1
		Mono-calcium Phosphate			
99	0	165.0	27.5	100.0	100.0
111	30	102.3	19.6	71.3	71.3
123	180	—†	18.9	68.6	68.6
135	365	71.2	2.1	7.6	7.6
		Di-calcium Phosphate			
101	0	249.2	28.5	100.0	103.5
113	30	131.5	21.4	75.0	77.9
125	180	122.3	9.1	31.9	33.1
137	365	75.5	3.7	13.0	13.4
		Tri-calcium Phosphate			
103	0	107.2	15.7	100.0	57.2
115	30	95.0	16.1	102.5	58.5
127	180	54.4	10.4	66.2	37.8
139	365	91.2	2.8	17.8	10.2
		Superphosphate			
105	0	287.3	32.2	100.0	117.1
117	30	112.4	25.9	80.4	94.2
129	180	120.3	24.1	74.9	87.6
141	365	77.2	2.1	6.5	7.6
		Ferric Phosphate			
107	0	17.2	6.8	100.0	24.7
119	30	20.0	9.1	133.8	33.1
131	180	18.4	5.7	83.8	20.7
143	365	23.6	5.4	79.3	19.6
		Mono-ammonium Phosphate			
109	0	80.1	30.2	100.0	109.9
121	30	120.3	26.6	88.1	96.7
133	180	81.1	14.5	48.0	52.7
145	365	28.0	3.6	11.9	13.1

*P_2O_5 equivalent to 2,000 pounds of 16% superphosphate.
†Lost.

The relationship between liming and available PO_4 as observed in this investigation is in close agreement with recent data of Pierre (3) which show that over-liming caused a decrease in the yield of corn in pot tests, but the amount of decrease from over-liming was greatly reduced as the phosphate level was raised with applications of superphosphate.

Preliminary tests similar to the one described here showed that, with low rates of superphosphate, the yields of oats and soybeans were decreased when $CaCO_3$ was applied at planting and this decrease

TABLE 3.—*The available PO_4 in a Vaiden clay and the yield of sorghum as affected by the application, at different periods before planting, of $CaCO_3$ and of low and high amounts of different phosphates.*

Pot No.*	Rate of phosphate application†	Number of days phosphated before planting	Number of days limed before planting	Available PO_4 Truog's method, p.p.m.	Yield in dry weight, grams	Relative yields
No Phosphate						
1	0	No phos.	No lime	10.0	0.6	2.1
147	0	No phos.	0	10.0	0.5	2.0
Mono-calcium Phosphate						
3	300	0	No lime	30.0	10.7	38.9
173		0	0	15.2	4.1	14.9
161		0	180	33.6	5.0	18.2
149		0	365	28.8	6.1	22.2
197		180	0	13.2	1.1	4.0
185		365	0	14.4	0.4	1.4
99	1,800	0	No lime	165.0	27.5	100.0
233		0	0	249.3	13.5	49.1
221		0	180	124.5	18.8	68.3
209		0	365	145.0	18.3	66.6
257		180	0	71.2	9.7	35.3
245		365	0	25.6	2.4	8.7
Di-calcium Phosphate						
5	300	0	No lime	48.8	9.0	32.7
175		0	0	61.6	1.3	4.7
163		0	180	65.5	1.8	6.5
151		0	365	71.2	1.0	3.6
199		180	0	14.4	1.8	6.5
187		365	0	16.8	0.4	1.4
101	1,800	0	No lime	249.2	28.5	103.5
235		0	0	311.2	14.2	51.6
223		0	180	226.5	16.5	60.0
211		0	365	174.0	18.2	66.2
259		180	0	87.7	9.3	33.8
247		365	0	71.0	3.7	13.4
Tri-calcium Phosphate						
7	300	0	No lime	20.8	5.6	20.4
177		0	0	22.4	0.9	3.2
165		0	180	56.0	0.6	3.2
153		0	365	23.2	0.4	1.4
201		180	0	14.4	0.9	3.2
189		365	0	18.0	0.4	1.4
103	1,800	0	No lime	107.2	15.7	57.2
237		0	0	73.7	5.7	20.7
225		0	180	91.2	0.5	1.8
213		0	365	112.0	0.4	1.4
261		180	0	71.2	2.9	10.5
249		365	0	71.2	2.1	7.6

*The treatments were in duplicates; only the averages are reported.

†In pound equivalents of superphosphate per acre.

TABLE 3.—*Concluded.*

Pot No.*	Rate of phosphate application†	Number of days phosphated before planting	Number of days limed before planting	Available PO_4, Truog's method, p.p.m.	Yield in dry weight, grams	Relative yields
			Superphosphate			
9	300	0	No lime	37.6	8.8	32.0
179		0	0	37.6	4.2	15.6
167		0	180	47.2	2.5	9.1
155		0	365	43.2	4.0	14.5
203		180	0	15.6	1.6	5.8
191		365	0	17.2	0.4	1.4
105	1,800	0	No lime	287.3	32.2	117.1
239		0	0	213.3	17.6	64.0
227		0	180	191.2	23.3	84.7
215		0	365	139.3	25.1	91.3
263		180	0	86.5	8.5	30.9
251		365	0	71.2	3.1	11.2
			Ferric Phosphate			
11	300	0	No lime	16.0	2.6	9.4
181		0	0	12.8	0.4	1.4
169		0	180	10.4	0.5	1.8
157		0	365	16.4	0.4	1.4
205		180	0	12.4	0.3	1.0
193		365	0	17.2	0.3	1.0
107	1,800	0	No lime	17.2	6.8	24.7
241		0	0	16.8	1.3	4.7
229		0	180	20.8	2.0	7.2
217		0	365	30.0	2.3	8.3
265		180	0	35.2	1.6	5.8
253		365	0	19.2	0.5	1.8
			Mono-ammonium Phosphate			
13	300	0	No lime	46.4	9.9	36.0
183		0	0	22.0	5.5	20.0
171		0	180	16.8	5.3	19.3
159		0	365	16.4	7.3	26.5
207		180	0	13.2	1.6	5.8
195		365	0	13.2	0.9	3.2
109	1,800	0	No lime	80.1	30.2	109.9
243		0	0	80.0	19.9	72.3
231		0	180	83.2	24.4	88.7
219		0	365	102.3	28.5	103.5
267		180	0	77.2	10.9	39.6
255		365	0	68.0	4.9	17.8

*The treatments were in duplicates; only the averages are reported.
†In pound equivalents of superphosphate per acre.

lessened as the period of $CaCO_3$-soil contact increased. Where high rates of superphosphate were used, the yields with $CaCO_3$ were greater than where no $CaCO_3$ was applied. The yields due to $CaCO_3$ increased as the time of the $CaCO_3$-soil contact increased up to a period of 1 year.

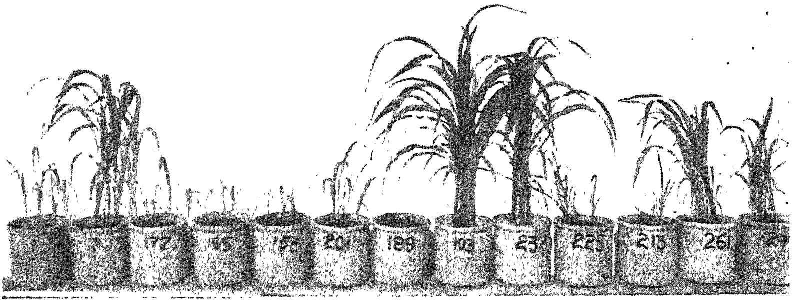

Fig 1.—Sorghum on Vaiden clay as influenced by applications of tri-calcium phosphate and $CaCO_3$ applied at various periods before planting. All pots received equivalent amounts of potassium and nitrogen. The basic phosphate treatment was equivalent to 300 pounds of superphosphate per acre. Lime applications were equivalent to 11.474 pounds of $CaCO_3$ per acre to bring the reaction to pH 6.5

1, no P; 7, P at planting, no lime; 177, P at planting, lime at planting; 165, P at planting, lime 180 days before planting; 153, P at planting, lime 365 days before planting; 201, P 180 days before planting, lime at planting; 189, P 365 days before planting, lime at planting; 103, 6P at planting, no lime; 237 6P at planting, lime at planting; 225, 6P at planting, lime 180 days before planting; 213, 6P at planting, lime 365 days before planting; 261, 6P 180 days before planting, lime at planting; 249, 6P 365 days before planting, lime at planting.

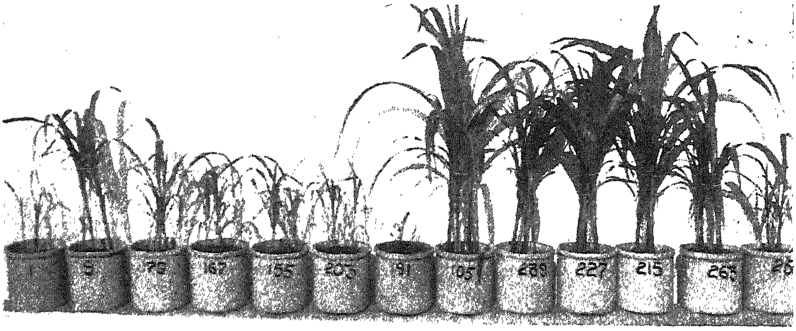

Fig. 2.—Sorghum on Vaiden clay as influenced by applications of superphosphate and $CaCO_3$ applied at various periods before planting. All pots received equivalent amounts of potassium and nitrogen. The basic phosphate treatment was equivalent to 300 pounds of superphosphate per acre. Lime applications were equivalent to 11,474 pounds $CaCO_3$ per acre to bring the reaction to pH 6.5.

1, no P; 9, P at planting, no lime; 179, P at planting, lime at planting; 167, P at planting, lime 180 days before planting; 155, P at planting, lime 365 days before planting; 203, P 180 days before planting, lime at planting; 191, P 365 days before planting, lime at planting; 105, 6P at planting, no lime; 239, 6P at planting, lime at planting; 227, 6P at planting, lime 180 days before planting; 215, 6P at planting, lime 365 days before planting; 263, 6P 180 days before planting, lime at planting; 251, 6P 365 days before planting, lime at planting.

CALCAREOUS SOIL

This experiment was similar to others conducted on Sumter clay soils from different areas in the Black Belt (4). The method of conducting this experiment was the same as for the acid soil; however, there was no $CaCO_3$ series and superphosphate was the only source of phosphorus used. The superphosphate was applied at the rates of 250, 500, 1,000, and 2,000 pounds per acre.

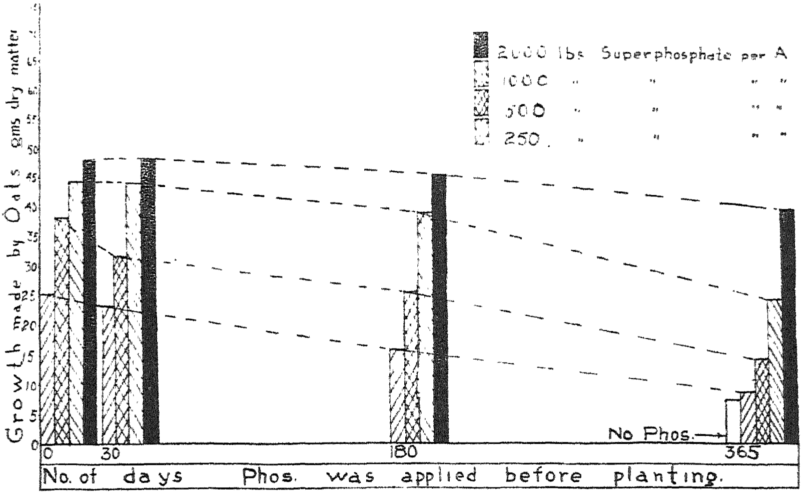

FIG. 3.—The effect of various rates and time of application of superphosphate on the yield of oats on a calcareous clay (Sumter clay).

The results reported are similar to those obtained with other soil samples of this type. Fig. 3 shows the effects of various rates of application and the time of application of superphosphate on the yields of oats. It should be noted that the yield of oats increased when the rate of application of superphosphate was increased from 250 to 2,000 pounds per acre. The yield of oats decreased as the period of phosphate-soil contact increased, this decrease being greatest with the lowest rates of phosphate applications. Where the phosphate had been in the soil 365 days, 250 pounds of superphosphate per acre produced a yield only slightly larger than where no phosphate had been applied, and the 1,000 pounds per acre produced a yield about equal to that produced by 250 pounds applied at planting time. These data show that calcareous clay soils, as well as acid clay soils, have great capacities for fixing phosphates and that the rate and degree of phosphate fixation in the two groups of soils are very similar, even though the nature of the fixation in the acid and alkaline soils may be different.

DISCUSSION

The results reported regarding the yield of crops with different types of phosphates as affected by liming present some facts that throw considerable light on the relationship between available PO_4 and lime in acid clay soils. Easily soluble and relatively insoluble phosphates have distinctly characteristic behaviors with lime.

When very soluble phosphates, such as mono-ammonium or mono-calcium phosphates, are added to an acid soil, the fixation of the PO_4 ion takes place as rapidly as the phosphate is diffused through the soil and comes in contact with the colloids. The extent of the fixation will be influenced by the type of colloid, the rate of the fixation, and the rate of diffusion. When $CaCO_3$ is added to the soil, it also must come in contact with the colloidal soil acids before equilibrium is established. All of the $CaCO_3$ did not react immediately with the soil acids, some of the calcium remaining in the soil solution as $CaCO_3$ and $Ca(HCO_3)_2$ which upon hydrolysis make the soil solution alkaline. The calcium in the soil solution probably united with the soluble phosphorus to form tri-calcium phosphate, thus lowering the availability of the phosphorus to the plants and decreasing the yield. When, at the end of 365 days, equilibrium between the $CaCO_3$ and the soil acids was reached, all the $CaCO_3$ had been used and the reaction of the soil solution was pH 6.5. Investigations with the soil colloids (5) showed that the applied phosphates were less available at alkaline than at either a neutral or an acid reaction. Therefore, when equilibrium was established in the soils with the $CaCO_3$, there was no free $CaCO_3$ present and more phosphorus was available and increased yields were obtained.

When a relatively insoluble phosphate, as tri-calcium phosphate, was added to an acid soil some phosphorus was probably made available by the soil acids and H_2CO_3. As shown in Table 2, the fixation of this form of phosphate was relatively slow. When the $CaCO_3$ was added, it did not all come in contact immediately with all the soil acids as explained before. Some of the soil acids were available to react with the tri-calcium phosphate to bring some phosphorus into solution. The solubility was reduced considerably by the calcium in the soil solution as compared with the availability of the phosphate without the $CaCO_3$ (pot 237 in Fig. 3 and data in Table 3). When equilibrium between the soil acids and the $CaCO_3$ was established and pH 6.5 was attained, as was the condition at the end of 365 days, the availability of the tri-calcium phosphate was very low as measured by plant growth.

With heavy rates of superphosphate, where lime gave increased yields of oats and soybeans with superphosphate, it is likely that these increases may be attributed to the calcium as a nutrient and not to any changes in the reaction of the soil. When superphosphate is applied to a soil at rates equivalent to 1 ton per acre, as is necessary for many of the heavy clay soils of Alabama in order to satisfy the phosphorus requirement of most plants, approximately 500 pounds of calcium is added. In a field experiment being conducted on a strongly acid Lufkin clay, the soil produced a large yield of corn and cotton without lime only where 1,600 pounds of superphosphate per acre were applied. The yield with 800 pounds of superphosphate and 2 tons of lime per acre was the same as the yield with the high rate of phosphate without the lime. The amount of $CaCO_3$

required by this soil to bring the reaction from pH 4.9 to 6.5 is 5 tons per acre, yet the 2 tons of lime maintained the yield when the superphosphate application was 800 pounds per acre. The yield with the 800-pound rate of superphosphate without the lime was much lower than that with the higher rate.

It is common practice in field experimental work to apply fertilizers to all soils on the basis of pounds per acre with no special regard to the variations in the texture of the soils. When full recognition is taken of the fact that the colloidal fraction of a soil is the seat of the major soil phenomena, it appears more logical to apply fertilizers, particularly phosphates, on the basis of pounds of fertilizers per unit of colloid in 2 million pounds of soil than to apply them at a fixed rate to all soils irrespective of differences in colloidal content. An application of 300 pounds of superphosphate per acre to a loamy sand with a 9% colloidal content is considered a moderate rate of application. This amount of phosphate was found to be practically lost, so far as increased yields were concerned, on the Black Belt soils of Alabama which have colloidal contents of over 50%. It was found that as much as 2,000 pounds of superphosphate per acre were necessary in order to obtain satisfactory yields. An application of 2,000 pounds per acre to a soil with a 60% colloidal content is equivalent to 300 pounds to a soil with a 9% colloidal content.

From the above findings it may be pointed out that phosphates would probably be more effective if added to soils in pellet-form. The diffusion of the phosphate and consequently the fixation would be decreased. Results of pot experiments conducted by one of the authors indicated that the phosphate was more efficient when added in localized zones than when mixed throughout the entire soil.

SUMMARY

The results may be briefly summarized as follows:

1. Maximum plant response to phosphate fertilization on highly colloidal acid and calcareous soils was not obtained until the applications of the phosphates were requvalent to 1,800 and 2,000 pounds of superphosphate per 2 million pounds of soil, respectively.

2. The efficiency of the various phosphates used, as measured by plant response, decreased rapidly with the time of contact with the soil.

3. In the acid soil, di-calcium phosphate was slightly more available than mono-calcium phosphate. The relative efficiencies for mono-calcium, tri-calcium, mono-ammonium, ferric phosphates, and superphosphate were 100, 57, 110, 25, and 117, respectively.

4. Calcium carbonate greatly decreased the availability of readily soluble phosphates and the crop yield when applied immediately before planting to the acid clay soil, whereas after equilibrium was established and $CaCO_3$ was no longer present in the soil the availability of the phosphates increased as shown by the yield of sorghum. Calcium carbonate decreased the availability of tri-calcium phosphate as measured by plant growth.

5. In general, the more soluble the phosphate used the more rapid was the rate of fixation. On the other hand, relatively insoluble

phosphates were fixed slowly but were inefficient in supplying available phosphorus to the plants.

LITERATURE CITED

1. KARRAKER, P. E. The delayed effect of liming. Soil Science, 24:147–148. 1927.
2. PIERRE, W. H., and WORLEY, S. L. The buffer method and the determination of exchangeable hydrogen for estimating the amounts of lime required to bring soils to definite pH values. Soil Science, 26:363–375. 1928.
3. ——— and BROWNING, G. M. The temporary injurious effects of excessive liming of acid soils in relation to the phosphorus nutrition of plants. 1933. Unpublished.
4. SCARSETH, G. D. Morphological, greenhouse, and chemical studies of the Black Belt soils of Alabama. Ala. Agr. Exp. Sta. Bul. 237. 1932.
5. ——— and TIDMORE, J. W. The fixation of phosphates by soil colloids. Jour. Amer. Soc. Agron., 26:138–151. 1934.
6. TRUOG, E. The determination of the readily available phosphorus in soils. Jour. Amer. Soc. Agron., 22:874–883. 1930

THE POTASSIUM-LIME PROBLEM IN SOILS[1]

HANS JENNY and E. R. SHADE[2]

One hundred years ago Dr. Nepomuk Fuchs (1),[3] working on cementing materials, casually observed that addition of lime to certain clays liberated potassium and sodium. The great agricultural chemist Liebig immediately recognized the significance of these experiments and wrote in his famous textbook (4): "They have explained the action of slacked lime upon soils, and *have thus furnished an invaluable means of liberating from the soil the alkalies which are indispensable to the existence of plants.*"

Today an authority (5) on potassium-calcium relationships writes just the opposite, namely: "*It is fallacious to expect that the addition of lime will accomplish any direct chemical liberation of soil potash in rock-derived soils.*" Inspection of present-day literature reveals a confusing situation which is highly deplorable, both from theoretical and practical standpoints. Most official textbooks on soils still adhere to Liebig's viewpoint, while various scientific journals repeatedly publish conflicting points of view.

It is the purpose of this paper to investigate experimentally the various claims advanced, and it is hoped that the results presented will clarify to some extent the difficult problem.

TECHNIC

The determination of the *saturation capacity* of the soil colloids used was based on a modification of Bradfield's method in that the time factor of the equilibrium was taken into consideration (3). For the *potassium* analyses silicon, aluminum, iron, calcium, and magnesium were first eliminated according to standard methods, and then potassium was determined by the modified perchlorate method of Smith and Ross (7). Measurements of pH were carried out with the quinhydrone method. For all experiments the time of reaction was 7 days. The systems were in equilibrium with the partial CO_2-pressure of the air, unless otherwise designated.

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[1] Contribution from the Department of Soils, Missouri Agricultural Experiment, Station, Columbia, Mo. Journal Series No. 360. Received for publication March 28, 1933.

[2] Assistant Professor of Soils and Research Assistant, respectively.

[3] Numbers in parenthesis refer to "Literature Cited," p. 170.

The systems were made up according to *symmetry concentrations* and *symmetry values*. The former term refers to the amount of salt added to the clay system, provided the salt concentration (dissolved and undissolved substance) is made equal to the number of exchangeable ions on the colloid. The ionic exchange, in percentage, observed at symmetry concentrations, is called symmetry value (3). The volume of the entire system must be indicated.

POTASSIUM LIBERATION AS AFFECTED BY THE NATURE OF THE COLLOIDAL COMPLEX

Three widely different colloidal aluminum silicates, namely, permutite, bentonite clay, and Putnam clay, and in addition several natural, modified and artificial soils were used for the potassium interchange experiments. The outcome of the trials was very consistent. *In every case the addition of $CaCO_3$ has liberated large amounts of potassium.* In the pure clay systems $CaCO_3$ increased the potassium content of the soil solution (supernatant liquid) from 230 to 2,300%. These data tend to support the ideas of the old school of agricultural chemists.

EFFECT OF ANIONS ON RELEASE OF ADSORBED K BY Ca

The validity of the laws of base exchange in relation to the potassium-lime problem has recently been challenged. The idea has been advanced that in the presence of certain critical anions, such as OH, CO_3, and HCO_3, the Ca ion will not liberate K, but on the contrary will depress its outgo from the surface of the colloidal particle (5, 6).

From Fig. 1, which shows base exchange isotherms for the compounds $CaCl_2$, $CaCO_3$, and $Ca(OH)_2$, it is clearly seen that all three calcium compounds exchange K. These experimental curves, especially that for $Ca(OH)_2$, speak against the dominance of K-repression by OH ions.

It was repeatedly found that in the K-colloid-$Ca(OH)_2$ systems more Ca is adsorbed than K released, indicating that parallel to the K-Ca replacement there seems to exist an adsorption of $Ca(OH)_2$ because both the anion and the cation disappear as judged from Ca analyses and OH titration. If one would assume that the OH disappearance is due to HOH formation as a result of H-Ca exchange, the conclusion would follow that the Putnam colloid used has a saturation capacity of over 250 milliequivalents per 100 grams of colloid, which represents a value never obtained by the usual base exchange and titration methods. The problem of Ca adsorption from $Ca(OH)_2$ needs further investigation.

Table 1 shows that free *Ca replaces K in the presence of all of the important anions of the soil solution, viz.*, Cl, SO_4, PO_4, OH, HCO_3, CO_3.

TABLE 1.—*Effect of anions on the release of adsorbed K by Ca ions, symmetry values, except Nos. 3 and 6.*

No.	Anion associated with Ca	Nature of system			K in solution in absence of calcium %	K in solution after addition of calcium %	pH (final)	
		Material	Solid: liquid (clay conc.)	M.E. K per 100 grams colloid (initial)			Sol	Supernatant liquid
1	Cl	K—Putnam clay	1:100	60	4.63	64.03	6.76	6.78
2	SO_4	K—Putnam clay	1:100	68	7.24	68.23	7.00	6.10
3	PO_4	K—Permutite (Ungerer 8)	1:50	347	—	4.47	—	>9
4	OH	K—Putnam clay	1:100	68	7.24	47.85	—	—
5	OH	K—Permutite	1:400	273	>1.11	49.52	—	—
6	HCO_3	K—Putnam clay	1:100	68	7.24	82.50	6.14	7.50
7	HCO_3	K—Permutite	1:273	273	1.11	61.50	—	7.55
8	CO_3	K—Putnam clay	1:100	68	7.24	32.21	8.26	7.74
9	CO_3	K—Putnam clay (gel)	1:13	68	About 3	9.94	—	7.64
10	CO_3	K—Putnam clay	1:100	60	4.63	40.73	8.5	—
11	CO_3	K—Bentonite	1:130	90	—	40.32	7.98	7.70
12	CO_3	K—Permutite	1:273	273	1.11	26.56	—	8.02

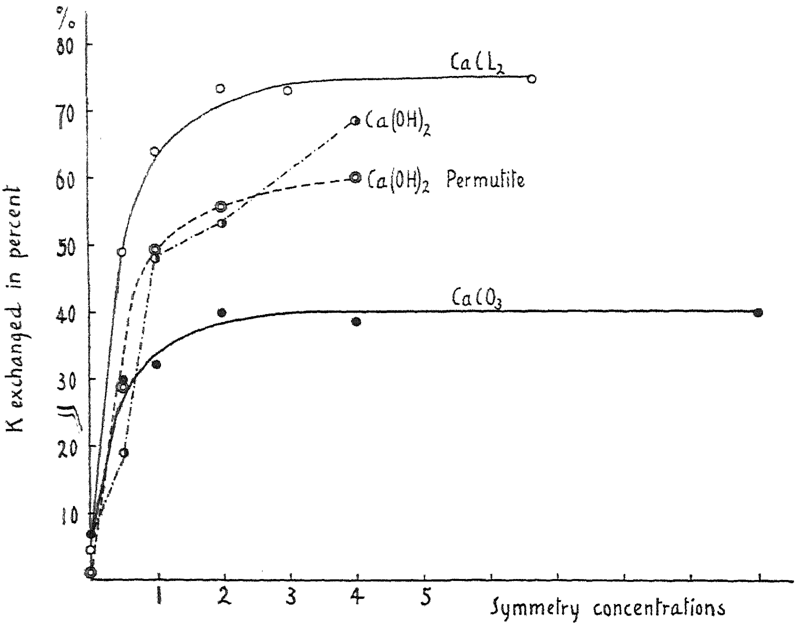

FIG. 1.—Base exchange isotherms (constant volume) for K-Putnam clays and K-permutite with various Ca compounds. (Compare Table 1, Nos. 1, 4, 5, 8.)

INFLUENCE OF CARBON DIOXIDE ON THE RELEASE OF K BY $CaCO_3$

Calcium carbonate is only slightly soluble in water, but in the presence of CO_2 it dissolves rapidly in the form of $Ca(HCO_3)_2$. One might easily expect an increase in the K-replacement by $CaCO_3$ if CO_2 is added to the system, due to the larger number of Ca ions and perhaps also on account of H ions which have a strong replacing power (3). According to the results given in Table 2, *the CO_2 effect is indeed very great. Comparatively large amounts of K are exchanged,* which is especially noticeable in the case of the K-Putnam clay system, which contains $CaCO_3$ in excess permitting a maximal Ca-bicarbonate formation.

TABLE 2.—*Effect of CO_2 on the release of K by $CaCO_3$.*

System	Potassium exchanged, %		pH of clay sol
	K—permutite	K—Putnam clay	
K—colloid+H_2O (at partial CO_2 pressure of air)	1.11	7.24	7.86
K—colloid+$CaCO_3$ (at partial CO_2 pressure of air)	26.56	32.21	8.26
K—colloid + H_2CO_3 (saturated with CO_2)	48.96	36.82	5.36
K—colloid+$CaCO_3$+H_2CO_3 (saturated with CO_2)	61.50	82.50	6.14

EFFECT OF ADSORBED H IONS ON THE K REPLACEMENT BY $CaCO_3$

Many soils of humid regions carry considerable amounts of exchangeable H ions in the colloidal complex. From the standpoint of soil management the following question is of considerable interest: If $CaCO_3$ is added to a colloidal system which contains exchangeable K, as well as exchangeable H ions, will the lime first neutralize the H ions and then replace the K, or will the exchange of K and H take place simultaneously? The experimental investigations of this question have been divided into three phases as follows:

1. *Acid systems* in which the adsorbed H ions on the colloidal particle exceed the number of ½$CaCO_3$ molecules added.
2. *Neutral systems* in which the $CaCO_3$ added is equal to the exchange acidity of the untreated soil.
3. *Alkaline systems* in which the $CaCO_3$ added is in excess of the H ions originally present.

The outcome of the study is shown in Table 3. In all these systems the K removal by mere hydrolyses (CO_2 present) is small, amounting to about 3%. *As soon as $CaCO_3$ is added large amounts of K are replaced in every case,* even in the acid system where not enough $CaCO_3$ had been introduced to neutralize all the exchangeable H ions.

Table 3 also illustrates the interesting fact that in a clay sol with $CaCO_3$ added in excess of the exchangeable H ions the K replacement is the greater the lower the degree of saturation. In other words, the more acid the soil the more pronounced is the K liberation by liming.

TABLE 3.—*Release of adsorbed K and H by $CaCO_3$.**

System	M.E. K on clay (initial)	M.E. H on clay (initial)	K in solution in absence of $CaCO_3$ %	M.E. $CaCO_3$ added	K released %	pH (final)
						sol
Acid system....	2.720	2.720	2.94	1.360	8.92	6.17
Neutral system	2.720	2.720	2.94	2.720	30.17	6.87
Alkaline system.	4.080	1.360	3.31	5.440	38.45	7.72
Influence of degree of saturation:						
25% saturated..	4.080	12.240	1.69	16.320	53.23	7.37
50% saturated..	4.080	4.080	2.94	8.160	52.49	7.69
75% saturated..	4.080	1.360	3.31	5.440	38.45	7.72
100% saturated.	4.080	0.000	6.30	4.080	32.05	7.95

*Putnam clay colloid, 1% sols, saturation capacity = 68 M.E. per 100 grams.

As to the interpretation of the absolute values of the exchange magnitudes, it is necessary to recall the procedures in the technic of the experiment. After addition of $CaCO_3$ powder to the H-K-clay sols, the flasks were immediately stoppered and sealed in order to prevent the loss of CO_2, which is formed as a result of the Ca-H interchange. After 7 days the stoppers were removed and the flasks were left open for 24 hours. This quite arbitrary procedure may simulate in a way natural soil conditions.

TIME AS A FACTOR IN K FIXATION

Previous experiments on ionic exchange (3) have indicated that adsorbed ions, such as K and Na, are more difficultly replaced from old systems than from young ones. Re-investigation of this phenomenon confirmed the observation for NH_4 colloids and to a lesser degree for K systems. Although this effect may be an important factor in the K availability over long periods of time, it is not considered to be significant for the potassium-lime problem.

MICROBIOLOGICAL EXPERIMENTS

Without a single exception, all laboratory experiments performed by the authors show that $CaCO_3$ liberates adsorbed K from soil colloids. In spite of these positive tests, the fact remains that various investigators consistently report observations which point toward an occasional depressive effect of lime upon K outgo. Credit is due to MacIntire (5) for emphasizing these abnormalities, although in the light of the present investigation his explanations do not seem to be tenable.

One of the main differences between "test tube" and "field" base exchange reactions is life, particularly microbiological life. In Table 4 the effect of micro-organisms on the leaching of soil rich in exchangeable K is summarized and reveals certain very interesting aspects.

TABLE 4.—*Effect of micro-organisms on the leaching of potassium from soils with high contents of exchangeable potassium.*

Systems investigated	Amount of K leached out by distilled water, M.E.			
	Sterile soil		Inoculated soil	
	No $CaCO_3$	With $CaCO_3$	No $CaCO_3$	With $CaCO_3$
	C	D	A	B
I. Artificial permutite soil: 200 grams quartz sand+16 grams filter paper+54.4 M.E. K—permutite+NH_4-, Ca-, Mg-permutite+0.5 grams $FePO_4$+H_2O±13.85 grams $CaCO_3$, steam sterilized, ±inoculated with soil extract, reaction time = 74 days.	0.931	2.681	0.821	2.289
[illegible] Soil+K—permutite: 400 grams Putnam silt+27.2 M.E. K—permutite±8 grams $CaCO_3$, ±chloroform sterilized, time = 112 days.	0.562	1.046	0.723	0.930
III. K—Putnam soil: 200 grams K—Putnam soil+6 grams red clover±4 grams $CaCO_3$+H_2O±sterilized, time = 112 days.	1.635	2.331	0.792	0.968

First, *the presence of micro-organisms has decreased the leaching of K* as compared with sterile soils (except in System II A), and this holds true both for systems "with" or "without" calcium carbonate. Secondly, the influence of $CaCO_3$ on the outgo of K is particularly significant. *Whenever micro-organisms are present, the increase of the K-outgo due to $CaCO_3$ is decidedly smaller than in the sterile systems.* Not only do micro-organisms reduce the leaching of K, but this reduction is particularly pronounced in the presence of lime. The probable cause of this behavior is revealed by analyses of the total and NH_4 nitrogen in System I, which indicates that in the presence of $CaCO_3$ the synthesis of microbiological bodies is greater than in absence of lime. The disturbing influence of micro-organisms on the K-$CaCO_3$ equilibrium is particularly pronounced in soils with low amounts of exchangeable K. From 2,228 grams of artificial, inoculated permutite soil (quartz sand+filter paper+dextrose+K-, NH_4-, Ca-, Mg-permutite+$FePO_4$, 56 days) containing 2.03 M.E. exchangeable K, as much as 0.468 M.E. K could be leached out with 1,000 cc of distilled water, while from a corresponding soil which had 10 grams of $CaCO_3$ added only 0.149 M.E. K could be recovered. Similarly, a modified Putnam silt loam containing much organic material showed 0.199 M.E. K in the soil solution when $CaCO_3$ was absent and only 0.162 M.E. K in the presence of lime. Thus, *under proper microbiological conditions an apparent reversal of the K-Ca interchange has been shown possible.* These interesting observations warrant further confirmation.

Data in Table 5 show that in a soil having a low K content *normal K-Ca replacement takes place in sterile systems and abnormal K outgo occurs in the presence of micro-organisms.* In the absence of micro-organisms the limed soil contains more K in the water extract than the unlimed one, while in the presence of living organisms the addition of $CaCO_3$ reduces the amount of easily soluble K. Evidently it is possible to demonstrate Liebig's contention as well as that of MacIntire so far as the resultant effects are concerned.

TABLE 5.—*Data showing that micro-organisms may cause an apparent reversal of K-Ca interchange.**

Soil system (low K level)	Amount of K leached out by 2,000 cc distilled water, M.E.		
	Sterile soil	Inoculated soil	Difference due to micro-organisms
No $CaCO_3$ added.......	0.530	0.276	—0.254
With $CaCO_3$ added......	0.899	0.222	—0.677
Difference due to $CaCO_3$	+0.369	—0.054	——

*Two thousand grams quartz sand + 367 grams Putnam silt loam + 160 gram[illegible] filter paper pulp + 15.26 grams urea ± 2 grams $CaCO_3$, sterilized, ± inoculated[illegible]

An attempt was made to locate the critical K level of a specific soil at which the apparent reversal of the K outgo takes place. Artificial permutite soils with low, medium, and high K contents (exchangeable) were prepared, inoculated, limed, and left standing for 147 days. The results of the K extraction with distilled water are given in Table 6 and clearly indicate that under given conditions *a critical K level really exists.* Below that critical value lime apparently "represses the solubility of K," above it, it increases the K content of the soil solution.

TABLE 6.—*Normal order and apparent reversal of K-Ca interchange as influenced by the K level of the soil in presence of micro-organisms.*

Nature of artificial soil	Extraction of K by H_2O, M.E.		
	In absence of $CaCO_3$	In presence of $CaCO_3$	Difference due to lime
Soil with low K content..	0.299	0.234	—0.065
Soil with medium K content.................	0.7824	0.7818	±0.0006
Soil with high K content	0.7	1.340	+0.640

Summarizing the results of the microbiological experiments, the following statement may be safely made: The contention of Liebig and his followers that lime liberates adsorbed K can be proven *in vitro*, but so can the contradictory field observations of MacIntire and his co-workers. The consideration of microbiological interference offers a possible way out of the dilemma and on this basis it is not necessary to assume any violation of base exchange principles, for which no definite proof has yet been furnished. These data strongly indicate *that $CaCO_3$ incorporated in the soil indeed liberates adsorbed K which in turn*—provided that conditions are favorable—*may be re-adsorbed by micro-organisms, the activity of the latter apparently having* *become favored by the treatment.* The authors believe that this aspect, which thus far has been entirely overlooked by the opponents of Liebig, may account, in part at least, for some of the abnormalities observed.

IONIC EXCHANGE IMPEDANCE

In the preceding discussion, the repression of the K solubility due to micro-organisms has been attributed solely to biological K fixation. Calculations indicate, however, that in some instances the depression of the K outgo reaches very high values and that the synthesis of micro-biological bodies can not be alone responsible. The authors are of the opinion that ionic exchange impedance also plays a rôle. Potassium permutite is a gel with small cavities and crevices in which the exchangeable K is seated. It is possible that the growing micro-organisms cover up part of the permutite surface (coating) and thus prevent the Ca ions from reaching the exchange localities on the colloidal particle. The micro-organisms, and perhaps the organic colloids formed, exert a protective action on the adsorbed K. They hinder or impede the normal ionic exchange reaction. According to an experiment on the NH_4-Permutite-KCl interchange in connection with the present study, the presence of small amounts of chloroform, starch, or gelatin reduced the normal exchange by 5 to 35% (ionic exchange impedance).

SUMMARY

1. Conflicting ideas as to the power of lime to liberate soil potassium are held by various investigators. Liebig's school believes that $CaCO_3$ makes K more available for plant growth, while certain modern workers take an opposite view and maintain that lime represses the outgo of K from soil colloids.
2. A re-investigation of the K-clay-$CaCO_3$ interchange with purified soil colloids, permutites, and natural and artificial soils reveals that in all systems investigated lime liberates adsorbed K in large quantities.
3. It could not be observed that OH and HCO_3 anions reduce the K replacement below the values obtained with ordinary distilled water; on the contrary pronounced exchange took place in the presence of such anions as Cl, SO_4, CO_3, HCO_3, OH, and PO_4.
4. Carbonic acid liberates considerable amounts of adsorbed K. If $CaCO_3$ is added to such a K-clay-H_2CO_3 system, a decided increase in the K outgo occurs which is attributed to the large number of Ca ions resulting from the formation of calcium bicarbonate.
5. In the presence of adsorbed H ions the replacement of K by $CaCO_3$ is intensified, provided that the resulting partial CO_2 pressure approaches that of soil air.
6. Micro-organisms reduce the leaching of K as compared with sterile systems. This reduction is most pronounced in the presence of $CaCO_3$.
7. Under a relatively low K level, but otherwise favorable micro-biological conditions, addition of $CaCO_3$ may actually cause a reduction of the K content of the soil solution below the value of the

unlimed soil which is attributed to biological re-adsorption of K and ionic exchange impedance.

8. It is believed that the occasional observations of the lack of K solubility and availability after liming are not necessarily violations of the general base exchange principles, but may be the result—in part at least—of interference by micro-organisms.

LITERATURE CITED

1. FUCHS, J. N. Über die Eigenschaften, Bestandteile und chemische Verbindung der hydraulischen Mörtel. Dinglers Polytechn. Jour., 49:271–296. 1833.
2. JENNY, H. Behavior of potassium and sodium during the process of soil formation. Mo. Agr. Exp. Sta. Res. Bul. 162: 1–63. 1931.
3. ————. Studies on the mechanism of ionic exchange in colloidal aluminum silicates. Jour. Phys. Chem., 36:2217–2258. 1932.
4. LIEBIG, J. Chemistry in its Application to Agriculture and Physiology. New York. 1847. (Page 128.)
5. MACINTIRE, W. H., SHAW, W. M., and YOUNG, J. B. The repressive effect of lime and magnesia upon soil and subsoil potash. Jour. Agr. Sci., 20:499–510. 1930.
6. MAGISTAD, O. C. Rate of loss of replaceable potassium by leaching. Soil Science, 30:243–256. 1930.
7. SMITH, G. F., and ROSS, J. R. The separation and determination of the alkali metals using perchloric acid. The precise estimation of the insoluble alkali metal perchlorates. Jour. Amer. Chem. Soc., 47:774–781. 1925.
8. UNGERER, E. Austauschreaktionen wasserunlöslicher Erdalkaliphosphate mit Permutiten und Tonen. Kolloid Zeitschr., 48:238–241. 1929.

AVAILABLE PHOSPHORUS IN SOIL AND THE PHOSPHORUS CONTENT OF GRAIN AS INFLUENCED BY PHOSPHORUS APPLICATIONS TO SOIL[1]

A. G. WEIDEMANN[2]

There were two main factors which prompted the investigations reported in this paper, namely, the power of certain soils to fix large quantities of phosphorus and hold it comparatively unavailable for plant use, and the possible effect of varying quantities of readily available phosphorus in soils on the phosphorus content of plants grown upon them. Preliminary investigations indicated that rather large quantities of phosphate fertilizer would have to be added to the soil under investigation before very much would be left readily available for plant use.

Considerable attention has been given to mineral content, especially the phosphorus content, of feed stuffs in relation to certain nutritional diseases of stock fed upon them. These diseases, according to Hart (3)[3] and others, have been quite definitely associated with the low phosphorus content of feeds grown in the region where the diseases occur. According to the investigations of Scott (10), the diseases are not caused by lack of lime in the forage crops of the affected areas of Montana, since the lime content of both the soils and the forage plants in those areas is ample. Analyses show the presence of a fair amount of phosphorus in the soils, but the low percentages of this element in the plants indicate that it is not very readily available for plant use.

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[2] Research Assistant. The writer wishes to express his appreciation to Dr. C. E. Millar for his helpful suggestions in carrying on the work and for reading and criticizing the manuscript.

[3] Figures in parenthesis refer to "Literature Cited," p. 178.

It occurred to the writer that if sufficient phosphorus could be added to the soil, along with other necessary plant food elements, so that a reasonable amount would remain readily available, it would result in an increased yield as well as an increased phosphorus content of feeds.

REVIEW OF LITERATURE

There are many papers bearing on the subject of the relationship between phosphorus content of soils, phosphorus fertilization, and phosphorus content of plants. Reference will be made here to only a few of the more important investigations. Holtz (5), working in Washington, found that the phosphorus content of oats followed closely the phosphorus content of some geologic soil classes, while that of clover followed the phosphorus content of the soil only in the case of organic soils. The calcium and phosphorus contents of oats grown in western Washington were lower than those in the same crop grown in the eastern and mid-western states, while those of clover were about the same in the three areas. The phosphorus content of oats followed closely the total phosphorus content of the soil, while that of clover followed more closely the available phosphorus content of the soil. A large number of oat samples from western Washington were lower in calcium and phosphorus than those reported by numerous investigators as being responsible for nutritional diseases. The average percentage of phosphorus in western Washington grown oats was given as 0.166, while that from certain other states, including central and eastern states, is given as ranging from 0.231% to 0.378%. In oat samples from different soils within western Washington, the percentages varied from 0.093 to 0.232, the highest figures being below the average reported from other states.

Ames, Boltz, and Stenius (1) draw the following conclusions: That the character of wheat is changed more by seasonal influences than by differences in soils or fertilizer treatments; that high starch content is associated with high phosphorus content and low protein content; and that to a certain extent the ratio of phosphorus to nitrogen in wheat stands in the same order as that of phosphorus to nitrogen in the soil. In their work the percentage of phosphorus in wheat was increased from 0.32 on the check plat to 0.37 where 20 pounds per acre of phosphorus were applied and 0.43 where 112 pounds of phosphorus were applied along with other fertilizing elements.

Blair and Prince (2) made analyses of crops grown in cylinders and on field plats that had been fertilized consistently for over 20 years and found that corn and oat plants grown with complete fertilizer and manure contain a higher percentage of phosphorus than those grown without fertilizer. Nitrogen in the complete fertilizer tended to decrease the percentage of phosphorus in these plants. With rye in some cases small applications of phosphorus decreased the percentages of this element in both grain and straw while larger applications increased them somewhat. Phosphorus content of wheat and oats grain grown where 20 pounds per acre of phosphorus were used was not consistently increased and in some cases it was decreased.

Truog (11) determined the phosphorus content of young plant material grown in quartz sand cultures containing various forms of phosphates. The percentages of phosphorus in plants grown in these cultures varied considerably, ranging in barley from 0.076 to 0.822, in corn from 0.088 to 0.565, in clover from 0.137 to 0.606, and in serradella from 0.141 to 0.574. In all cases the lowest percentage was associated with rock phosphate and the highest with magnesium phosphate.

According to Murphy (8), 300 pounds of 16% superphosphate per acre increased the yield of wheat in Oklahoma from 14 to 20.5 bushels and the phosphorus content of the grain from 0.320% to 0.397%. The yield from plats receiving phosphorus alone was nearly as high as from plats receiving any combinations of elements along with phosphorus.

Hartwell and Hammett (4) found that the phosphorus content of turnips grown on soil which received no phosphate treatment was only about 52% to 60% of that in turnips grown on soil that received in excess of a liberal amount of phosphate fertilizer.

Mitchell, Warner, and Morrow (7), working in South Carolina, reported that phosphorus in fertilizers decreased the calcium and magnesium content of oats and increased the phosphorus content of oats, grass hay, and soybean hay. They report a wide variation in the phosphorus content of feeds from different parts of the country. Minnesota alfalfa varied from 0.36% P_2O_5 to 0.65% P_2O_5, while grass hay varied from 0.19% P_2O_5 in New Jersey to 0.52% in Florida.

Mather (6), working in Minnesota and using applications of phosphorus ranging from 200 to 2,000 pounds per acre of treble superphosphate, reported that maximum increases in yields resulted from the use of about 200 pounds of the treble superphosphate, while large increases in phosphorus content of the plants resulted from the use of much larger applications. These increases in phosphorus content of the plants were found to be largely in the inorganic form. Some of the large applications of phosphorus increased the phosphorus content of various forage crops by percentages ranging from 69 to 175. The phosphorus contents of wheat and barley straw were increased by 150% and 100%, respectively, while those of the grains were not changed a particle by large applications of phosphorus to the soil. The above-mentioned increases were enormous in some cases, although not very consistent.

These citations indicate that there are great variations in the phosphorus content of plant material as affected by location, natural soil and climatic conditions, and fertilizer applications. Phosphorus fertilization increases the phosphorus content of forage plants, root crops, and straws much more than that of grain, as shown by certain investigations, especially those of Mather (6).

EXPERIMENTAL WORK

The soil on which this experiment was conducted is classified as Hillsdale sandy loam and the whole area involved was exceptionally level and uniform for that type of soil. The plats were laid out in duplicate in 1926, there being 12 plats of 0.0409 acre each. The soil, being acid in reaction, was given a uniform application of 2 tons of limestone per acre. In each set of duplicates there was one plat which received lime only. All other plats got a uniform application of urea, KCl, and $CaSO_4$. Only the phosphorus treatments varied and the acre applications of this element were as follows: Plat 1, 25 pounds C. P. $CaHPO_4$; plat 2, check; plat 3, 50 pounds C. P. $CaHPO_4$; plat 4, 100 pounds C. P. $CaHPO_4$; plat 5, C. P. $CaH_4(PO_4)_2$ equivalent to 100 pounds of C. P. $CaHPO_4$; and plat 6, no phosphorus. During the years 1926, 1927, 1928, and 1929, the plats grew corn, barley, sweet clover, and barley, respectively, without additional fertilizer applications, none of which showed a great deal of response to phosphate fertilizers.

FERTILIZERS USED AND CROPS GROWN

In the spring of 1930, fertilizer applications were made again with the idea in mind of studying the effect of different rates of application of phosphorus on the yield and composition of the crops and the amount of readily available phosphorus in the soil. These fertilizers and the ones used later were made from commercial carriers and their rates of application and composition are given in Table 1. The fertilizer applications made in the spring of 1930 were for oats. In the fall of 1930, rye was seeded on the plats without additional fertilization, and in the fall of 1931 the fertilizer applications were repeated and the plats seeded to wheat.

METHOD OF SAMPLING SOIL AND CROPS

The soil was sampled on November 12, 1930, after it had been seeded to rye; again on November 4, 1931, after it had been refertilized, fitted, and seeded to wheat; and again on November 10, 1932, while the plats were in wheat stubble. Twenty borings 1.5 inches in diameter and 6.5 inches deep were taken from as many spots uniformly distributed over the plat. These were put together, dried, sifted through a 20-mesh screen, thoroughly mixed, and stored for analysis. At the first sampling only the first six plats were sampled but later samplings included the duplicate plats as well.

Oats and rye were sampled by taking two rows across each plat when ready for harvest. In case of wheat, an effort was made to get a more representative sample by taking parts of rows at 20 different places uniformly distributed over each plat. Each sample made a bundle about 6 inches in diameter. These samples were dried, separated into grain, chaff, and straw, run through a Wiley mill using a screen of a little less than 1-mm mesh, thoroughly mixed, and stored for analysis.

METHODS OF ANALYSIS

The determinations of readily available phosphorus in these soil samples were made by use of the Truog (12) laboratory method. Phosphorus determinations on plant tissue were made according to the directions proposed by the Association of Official Agricultural Chemists. All determinations were made in duplicate on samples dried at 105° C, and many were replicated as many as six times to be sure of the reliability of the results. The results of soil analyses will be found in Table 1 along with the fertilizer treatments, while the yield and composition of the plants are given in Tables 2, 3, and 4.

TABLE 1.—*Rate of fertilizer application and the available phosphorus in the soil at different times.*

Plat No.	Treatment		Lbs. available P per acre		
	250 lbs. per acre	Lbs. P added per application	1930*	1931	1932
1.......	3-8-10	8.73	40.10	34.50	33.83
2.......	0-0-0	0.00	41.90	35.70	39.95
3.......	3-16-10	17.46	38.05	47.93	50.73
4.......	3-32-10	34.92	49.30	67.40	67.00
5.......	3-48-10	52.38	67.25	98.23	97.70
6.......	3-0-10	0.00	34.25	36.35	36.93
1A......	3-8-10	8.73		54.25	54.73
2A......	0-0-0	0.00		45.70	48.58
3A......	3-16-10	17.46		58.90	54.05
4A......	3-32-10	34.92		62.40	60.83
5A......	3-48-10	52.38		95.18	82.40
6A......	3-0-10	0.00		31.28	32.20

*These figures represent the amounts of readily available phosphorus after one application of fertilizer had been made. The other two columns of figures represent the same after a second application had been made.

DISCUSSION OF RESULTS

Table 1 exhibits some differences between the amounts of readily available phosphorus in soils of duplicate plats. Some of these differences might be due to inaccuracy in sampling, but it is quite likely that many of them are due to soil differences despite the fact that the soil seemed very uniform. Where small applications were made neither one nor two applications increased the available phosphorus content over that of the check plat in the first set of plats. Single applications of the larger quantities of phosphorus increased considerably the amount of readily available phosphorus in the soil and the second application still further increased the supply. Repeated applications of the small amounts failed to increase the amount of available phosphorus. It will be seen from a study of the last two columns of figures in Table 1 that the growing of a crop of wheat made very little change in the amount of readily available phosphorus in the soil.

Under Wisconsin conditions, Truog (12) has set the minimum limit of readily available phosphorus at 50 pounds per acre in the plowed layer of light soils. Assuming these conditions to hold true for the soil under investigation, it is logical to assume that the range found here is sufficient to produce considerable increase in yield and phosphorus content of crops, providing some other factor does not interfere.

In this investigation the oats and rye were grown on the soil after only one application of fertilizer had been made, while the wheat was grown after the second application had been made, hence we would expect greater differences with the wheat than with the oats or rye.

TABLE 2.—*Amount of phosphorus applied, amount of readily available phosphorus found in soil, and crop yield all on the acre basis, and phosphorus content of various parts of the oat plant in 1930.*

Plat No.	Lbs. P added spring 1930	Lbs. available P in soil fall 1930	Yield		P in crop, %		
			Bu. of grain	Lbs. of straw	Grain	Chaff	Straw
1	8.73	40.10	45.6	1,584	0.376	0.064	0.027
2	0.00	41.90	31.5	982	0.398	0.105	0.056
3	17.46	38.05	35.4	1,275	0.384	0.084	0.044
4	34.92	49.30	40.2	1,415	0.410	0.118	0.074
5	52.38	67.25	38.2	1,333	0.426	0.274	0.097
6	0.00	34.25	44.1	1,357	0.371	0.081	0.029
1A	8.73		48.1	1,448	0.403	0.105	0.043
2A	0.00		30.7	1,100	0.407	0.134	0.076
3A	17.46		48.1	1,551	0.364	0.056	0.025
4A	34 92		42.3	1,700	0.411	0.187	0.039
5A	52.38		42.8	1,353	0.387	0.094	0.049
6A	0.00		41.2	1,361	0.376	0.088	0.031

RESULTS WITH OATS

All fertilizer applications resulted in an increased yield of oats, but there was no correlation between quantity of phosphorus applied and yield. There was an increase in phosphorus content of grain due to increased application of phosphorus to the first set of plats. This correlation, however, did not hold true for the duplicate plats. In case of chaff and straw the same relation held true between treatment and phosphorus content of this material as was found with the grain, although differences in phosphorus content due to treatment, or some other cause, were greater with chaff and straw than with grain.

The chief discrepancies in the relationship between the phosphorus applications and the phosphorus content of the plants in the two sets of plats were found in the second set, or the "A" plats. A comparatively high percentage of phosphorus was found in the plants grown on the check plat and on the plat which received the smallest phosphorus application. The phosphorus content of plants grown on plat 4A was also much higher than that of the plants grown on plat 5A, which is in inverse proportion to the amounts of phosphorus applied to the soil. These statements apply especially to the phosphorus content of grain and chaff.

TABLE 3.—*Amount of phosphorus applied, amount of readily available phosphorus found in soil, and yield of crop, all on the acre basis, and phosphorus content of various parts of the rye plant in 1931.*

Plat No.	Lbs. P added spring 1930	Lbs. available P in soil fall 1930	Yield		P in crop, %		
			Bu. of grain	Lbs. of straw	Grain	Chaff	Straw
1	8.73	40.10	24.0	2,653	0.467	0.272	0.123
2	0.00	41.90	21.3	2,256	0.491	0.283	0.119
3	17.46	38.05	22.2	2,308	0.485	0.348	0.178
4	34.92	49.30	22.9	2,429	0.501	0.399	0.207
5	52.38	67.25	18.8	2,062	0.503	0.414	0.233
6	0.00	34.25	21.1	2,272	0.496	0.318	0.165
1A	8.73		25.9	2,790	0.494	0.339	0.173
2A	0.00		23.0	2,460	0.488	0.277	0.141
3A	17.46		23.9	2,587	0.494	0.320	0.160
4A	34.92		22.9	2,419	0.496	0.313	0.159
5A	52.38		22.0	2,313	0.497	0.367	0.171
6A	0.00		22.7	2,397	0.487	0.286	0.117

RESULTS WITH RYE

The range in the magnitude of yields of rye from different plats was not so great as was true with oats, although the yields from the check plats were slightly lower than those from the adjacent plats. The large applications of phosphorus did not materially increase the yield in any case over that from plats receiving no phosphorus; and the highest yields were obtained from the plats receiving the smallest application of phosphorus.

The phosphorus content of the rye grain from the check plat of the first set was a little higher than that of grain from adjacent plats which received small applications of phosphorus. The same observations were made with oats. With that one exception there was a fairly close relationship between the phosphorus content of the rye grain and the amount of readily available phosphorus in the soil. These variations in composition of grain due to treatment were indeed very slight.

A rather consistent relationship exists between treatment and composition of chaff and straw as well as a much greater range of differences in phosphorus content in these parts of the plant than in the grain. It might be noted that the phosphorus content of the plant material of both oats and rye from plat 1A is greater than that from plat 1. There are no figures to show the differences between the content of readily available phosphorus in the soils of these two plats when oats and rye were grown on them, but figures obtained in 1931 and 1932 after another fertilizer application had been made showed a much higher readily available phosphorus content of plats 1A, 2A, and 3A than of plats 1, 2, and 3. This fact might indicate a greater natural readily available phosphorus content of the 1A, 2A, and 3A plats and might account for the discrepancies mentioned above.

TABLE 4.—*Amount of phosphorus applied, amount of readily available phosphorus found in soil, and crop yield, all on the acre basis, and phosphorus content of various parts of the wheat plant in 1932.*

Plat No.	Lbs. P added fall 1931	Lbs. available P in soil		Yield		P in crop, %		
		Fall 1931	Fall 1932	Bu. of grain	Lbs. of straw	Grain	Chaff	Straw
1	8.73	34.50	33.83	26.7	2,590	0.470	0.134	0.071
2	0.00	35.70	39.95	23.4	1,948	0.471	0.116	0.066
3	17.46	47.83	50.73	22.9	2,073	0.480	0.160	0.076
4	34.92	67.40	67.00	23.5	2,087	0.473	0.162	0.074
5	52.38	98.23	97.70	22.2	1,829	0.476	0.167	0.083
6	0.00	36.35	36.93	22.3	1,891	0.469	0.128	0.071
1A	8.73	54.25	54.73	25.8	2,259	0.479	0.160	0.079
2A	0.00	45.70	48.58	23.5	1,987	0.465	0.120	0.074
3A	17.46	58.90	54.05	28.3	2,561	0.472	0.117	0.067
4A	34.92	62.40	60.83	26.7	2,326	0.462	0.104	0.056
5A	52.37	95.18	82.40	27.7	2,623	0.475	0.111	0.070
6A	0.00	31.28	32.20	24.3	2,154	0.461	0.127	0.063

RESULTS WITH WHEAT

Wheat was grown after the second application of fertilizers had been made, which resulted in a much increased quantity of readily available phosphorus, especially in the soils of plats receiving large applications. It is evident, from a consideration of the data in Table 4, that the yields of wheat were not consistently influenced by the quantity of phosphorus applied. Neither can it be said that there is any relationship between the amount of this readily available phosphorus and the phosphorus content of the wheat grain. There was a fairly consistent relationship between the amount of readily available phosphorus in the soil and the phosphorus content of chaff and straw from the first set of plats. There were also large differences between the phosphorus content of chaff and straw from different plats of the second set, but these differences bore no relationship to the amount of readily available phosphorus in the soils of these plats.

These results seem to support the work of Mather (6) in which he found that phosphorus applications to the soil did not influence the content of that element in the grain of wheat and barley, although they did influence it in the straw.

SUMMARY AND CONCLUSIONS

Data were obtained on the power of the soil under investigation to fix phosphorus and hold it unavailable for plant use. Also, a study was made of the relationship of phosphorus application to yield and phosphorus content of plants grown on this soil.

Various rates of application of phosphorus were made with fixed quantities of nitrogen and potash. Determinations were made of the amount of readily available phosphorus in the soil from the various plats at different times during the course of the investigation, and the phosphorus contents of different parts of the ripe oat, rye, and wheat plants were determined.

It was found that the untreated soil contained somewhat less readily available phosphorus than the amount suggested by Truog as being sufficient for crop production on similar types of soil under Wisconsin conditions.

About 400 pounds of 20% superphosphate per acre were required to produce a measurable increase in the amount of readily available phosphorus in the soil.

The results of the investigation show no consistent increase in yield of any of the crops grown due to applications of phosphorus in addition to nitrogen and potash.

The increases in phosphorus content of grain, if any, due to phosphorus applications to the soil were slight and usually inconsistent.

The increases in phosphorus content of chaff and straw due to these treatments were very noticeable in some cases, although not very consistent.

Judging from the results of this work, it would seem more advisable, as Mather (6) suggests, to add phosphorus directly to the rations of animals, where needed, through the use of bone meal or some other carrier rather than to try to increase the phosphorus content of grain through the application of phosphorus to the soil, since what increases in phosphorus are obtained in this way are usually not in the grain but in the portion of the plant not commonly used as feed.

LITERATURE CITED

1. AMES, J. W., BOLTZ, G. E., and STENIUS, J. A. Effect of fertilizers on the physical and chemical properties of wheat. Ohio Agr. Exp. Sta. Bul. 243. 1912.
2. BLAIR, A. W., and PRINCE, A. L. The influence of phosphates on the phosphoric acid content of the plant. Jour. Agr. Res., 44: 579–590. 1932.
3. HART, E. B. Phosphorus deficiency and the dairy cattle "disease." Wis. Agr. Exp. Sta. Bul. 389. 1927.
4. HARTWELL, B. L., and HAMMETT, F. S. The effect of phosphorus manuring on the amount of inorganic phosphorus in the flat turnip root. Jour. Ind. Eng. Chem., 3:831–832. 1911.
5. HOLTZ, Henry F. Effect of calcium and phosphorus content of various soil series in western Washington upon the calcium and phosphorus content of oats, red clover, and white clover. Wash. Agr. Exp. Sta. Bul. 243. 1930.
6. MATHER, T. H. The effect of fertilizers upon the forms of phosphorus, and the amount of phosphorus, nitrogen, and silica in hay. Sci. Agr., 10:35–63. 1929.
7. MITCHELL, J. H., WARNER, J. D., and MORROW, K. S. The mineral content of feeds, soils, and waters of South Carolina. S. C. Agr. Exp. Sta. Bul. 252. 1928.
8. MURPHY, H. F. Effect of fertilizer on the phosphorus content and yield of wheat. Jour. Amer. Soc. Agron., 22:765. 1930.
9. NELLER, J. R. The influence of sulfur and gypsum on the yield and composition of legumes. Wash. Agr. Exp. Sta. Bul. 190. 1925.
10. SCOTT, SAMUEL G. Phosphorus deficiency in forage feeds of range cattle. Jour. Agr. Res., 38:113–130. 1929.
11. TRUOG, E. The utilization of phosphates by agricultural crops including a new theory regarding the feeding power of plants. Wis. Agr. Exp. Sta. Res. Bul. 41. 1916.
12. ————. The determination of readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874. 1930.

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THE EFFECT OF THE TIME OF CUTTING AND OF WINTER PROTECTION ON THE REDUCTION OF STANDS IN KANSAS COMMON, GRIMM, AND TURKESTAN ALFALFAS[1]

C. O. GRANDFIELD[2]

The time of cutting alfalfa has been given consideration intermittently for the past 30 years. While the earlier experiments were conducted primarily to obtain information on the quality of hay, the observations made in connection therewith clearly indicated a correlation between the time of cutting and the maintenance of stand. The observations of Cotrell (3)[3] and Bennett (2) seemed to show that early and frequent cuttings stimulated growth, thereby producing more and higher quality hay. Later experiments reported by Williams and Kyle (14) indicated that alfalfa may be injured by cutting too early or by delaying cutting too long.

Numerous experiments have been conducted to study the effect of the time and frequency of cutting alfalfa. Moore and Graber (9), Salmon, *et al.*, (13), and Kiesselbach and Anderson (7) are among those who have reported on this subject and in all cases it was observed that too frequent or too late cuttings injured the stands of alfalfa. Not until the later reports were made was much attention given to the effect of the various cutting treatments on the plant itself.

Two methods of approach to the problem of maintaining stands of alfalfa are evident, first, that of varietal resistance to disease and winterkilling, and second, that of maintaining the vitality of the plant, thereby helping it to overcome such adverse conditions as killing by low temperatures or by partial freezing and the subsequent bacterial invasion as mentioned by Janssen (5) and by Jones and Weimer (6). Salmon (12) pointed out that some varieties are more resistant than others to bacterial wilt, and Peltier and Tysdal (10, 11) brought out the resistance of varieties to both cold and wilt.

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[2] Assistant Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture.

[3] Numbers in parenthesis refer to "Literature Cited," p. 188.

The experiment on which this paper is based was planned with consideration for both winterkilling and bacterial wilt, emphasis being placed upon the winter protection offered by the growth accumulating subsequent to the last cutting in the fall.

METHODS

The experiment reported here was started in the summer of 1929 on an apparently uniform field of bottom land in which adjoining areas were seeded to Kansas common, Grimm, and a strain of Turkestan, F. C. I. 2674, alfalfa in the fall of 1928. These three varieties are of particular interest to this region due to their different reactions to wilt and cold. Grimm is known to be susceptible to wilt but is winter hardy. Turkestan F. C. I. 2674 has shown both wilt and cold resistance, and Kansas common, the variety generally grown in this region, is intermediate in regard to both factors.

Fifteen duplicated treatments were planned, as shown by the outline of the experiment in Table 1, including variations in the number of cuttings, in the stage of bloom at which cuttings were made, winter protection afforded by varying the amount of growth left uncut in the field, and in the length of time between the last cutting and the time growth ceased in the fall. Each plat crossed the three varieties thus giving comparisons for all the treatments on all three varieties. Thirty 1/20 acre plats, 10 x 217.8 feet, were used.

To obtain information on winter protection, the experiment included four different treatments in which the duplicate plats received the same treatment through the growing season, but through the winter one plat of each pair was protected by the top growth accumulating after the last cutting, while the other was left unprotected by removing the crop after growth ceased in the fall. The length of the growing period after the last cutting ranged from 0 to 120 days.

In order to estimate the effect of the treatments, the stands were determined by counting the number of plants in circular areas of 1 ten-thousandth of an acre, selected at random. Five such areas were counted in the Kansas common and Grimm and three in the Turkestan, the crowns being carefully examined to ascertain the number of plants. At the close of the experiment, the stands of Kansas common and Grimm were so thin in several of the plats that random sampling of small areas was deemed unsatisfactory and counts were made on the representative areas of 100 square feet in each plat. The amount of bacterial wilt was determined by carefully examining for wilt symptoms the roots of all the plants in a uniform area 7 inches wide and 30 feet long in the Kansas common and Grimm and 17 feet long in the Turkestan each fall.

Although these plats were established on a field considered to be very uniform, it became evident that some soil and topographic differences existed. It is recognized that such variations should be measured and taken into account in interpreting the results. Salmon (12) discussed the desirability of using the probable error of the experiment, as suggested by Hayes (4), in such an experiment as this,

TABLE 1.—*Outline of plat treatments.*

Plat Nos.	Treatment by cuttings				
	First	Second	Third	Fourth	Fifth
1, 16	Tenth bloom†	Left for winter protection	———	———	———
2, 17	Tenth bloom	Removed in late fall	———	———	———
3,* 18*	Tenth bloom	Full bloom	Full bloom	Full bloom	
4, 19	Full bloom	Full bloom	Left for winter protection	———	———
5, 20	Full bloom	Full bloom	Removed in late fall	———	———
6, 21	Full bloom	Full bloom	Sept. 1	Left for winter protection	———
7, 22	Full bloom	Full bloom	Sept. 1	Removed in late fall	———
8*, 23*	Tenth bloom	Full bloom	Full bloom	Full bloom	
9, 24	Full bloom	Full bloom	Sept. 15	Left for winter protection	———
10, 25	Full bloom	Full bloom	Sept. 15	Removed in late fall	———
11, 26	Full bloom	Full bloom	Oct. 1		
12, 27	Bud	Bud	Bud	Bud	Bud
13,* 28*	Tenth bloom	Full bloom	Full bloom	Full bloom	
14, 29	Full bloom	Full bloom	Sept. 1 and clipped every 10 days thereafter	———	———
15, 30	Full bloom	Seed	Left for winter protection	———	———

*Used as checks.

†Abbreviations as follows are hereafter used in tables in this report: 1/10 B = Tenth bloom; FB = Full bloom; B = Bud.

and so probable errors of the stand counts are calculated from data obtained from the check plats.

PRESENTATION OF RESULTS

At the time the plats were established, the stands in the three varieties as determined by the hoop method were 834,000 plants per acre for Kansas common, 922,000 for Grimm, and 765,000 for Turkestan. Each spring, counts were made to determine the effect of the different treatments on the stand. These counts are presented for each variety in Table 2 with the percentage reduction in the number of plants each year and the total reduction for the 2-year period. The probable errors of the stand counts for each year are given at the bottom of the respective columns.

In order to show more clearly the varietal differences in Table 2, the average of the stand counts of the 30 plats for each variety are pre-

TABLE 2.—*Number of plants per acre and percentage reduction as determined by spring stand counts.*

Cutting treatment*	Winter treatment†	Plat No.	Number of plants per acre (000 omitted)									Annual and total percentage reduction								
			Kansas common			Grimm			Turkestan			Kansas common			Grimm			Turkestan		
			1930	1931	1932	1930	1931	1932	1930	1931	1932	1930 to 1931	1931 to 1932	1930 to 1932	1930 to 1931	1931 to 1932	1930 to 1932	1930 to 1931	1931 to 1932	1930 to 1932
1/10 B	P	1	542	328	53	668	260	57	556	293	246	39	84	90	61	78	91	47	16	56
1/10 B	E	2	586	316	47	564	256	31	470	296	218	46	85	92	55	88	95	37	26	54
B-FB-FB-FB		3	484	304	42	588	300	45	516	336	258	37	86	91	49	85	92	35	23	50
FB-FB	P	4	550	302	103	588	340	99	540	346	247	45	66	81	42	71	83	36	29	54
FB-FB	E	5	528	308	51	626	292	54	453	306	203	42	83	90	53	82	91	32	34	55
FB-FB Sept. 1	P	6	422	238	108	544	344	103	480	390	248	44	55	74	37	70	81	19	36	48
FB-FB Sept. 1	E	7	480	310	51	552	252	47	500	310	205	35	84	89	54	81	91	38	34	59
B-FB-FB-FB		8	496	324	51	482	242	49	466	326	233	35	84	90	50	80	90	30	29	50
FB-FB Sept. 15	P	9	488	324	98	412	254	100	410	300	215	34	70	80	38	61	76	27	28	48
FB-FB Sept. 15	E	10	422	308	55	518	248	53	526	390	239	27	82	87	52	79	90	26	39	55
FB-FB Oct. 1		11	538	304	82	482	256	57	463	333	217	43	73	85	47	78	88	28	35	53
B-B-B-B-B		12	334	204	27	476	280	19	340	233	164	39	87	92	41	93	96	31	30	52
B-FB-FB-FB		13	382	288	47	486	254	35	360	276	208	25	84	88	48	86	93	23	25	42
FB-FB Sept. 1‡		14	442	296	30	446	246	20	420	350	194	33	90	93	45	92	96	17	45	54
FB-seed		15	394	260	102	440	284	103	340	250	211	34	61	74	35	64	77	26	16	38
1/10 B	P	16	476	262	99	684	278	95	493	286	231	45	62	79	59	66	86	42	19	53
1/10 B	E	17	466	274	36	544	250	18	480	276	201	41	87	92	54	93	97	43	27	58
B-FB-FB-FB		18	396	258	26	564	184	15	446	316	221	35	90	93	67	92	97	29	30	50
FB-FB	P	19	438	276	91	450	232	92	460	323	219	37	67	79	48	60	80	30	32	52
FB-FB	E	20	408	258	46	500	206	54	433	303	196	37	82	89	59	74	89	30	35	55
FB-FB Sept. 1	P	21	386	244	101	488	262	106	420	323	196	37	59	74	46	60	78	23	39	53
FB-FB Sept. 1	E	22	392	248	41	482	190	33	363	250	171	37	83	90	61	83	93	31	32	53
B-FB-FB-FB		23	384	248	46	470	264	37	476	310	238	35	81	88	44	86	92	35	23	50
FB-FB Sept. 15	P	24	374	270	78	430	238	79	390	300	219	28	71	79	45	67	82	23	27	44
FB-FB Sept. 15	E	25	360	266	34	444	224	20	446	323	187	26	87	91	50	91	95	28	42	58
FB-FB Oct. 1		26	460	262	68	448	264	43	340	256	172	43	74	85	41	84	90	25	33	49
B-B-B-B-B		27	294	202	26	462	292	11	376	253	172	31	87	91	37	96	98	33	32	54
B-FB-FB-FB		28	336	212	33	460	276	18	310	250	182	37	84	90	40	93	96	19	27	41
FB-FB Sept. 1‡		29	312	166	19	412	190	8	373	280	166	47	89	94	54	96	98	25	41	55
FB-seed		30	328	242	83	432	252	84	370	293	201	26	66	75	42	67	81	21	31	46
P. E. diff. between any 2 plats			±55	±36	±8	±47	±35	±12	±68	±29	±23									

*See Table 1 for explanation of symbols. †P = Protected; E = Unprotected. ‡Clipped.

sented in Table 3. The rapid decline in the number of plants in both the Kansas common and Grimm and the more nearly normal loss in the Turkestan are also shown.

TABLE 3.—*Average number of plants per acre and percentage reduction in stands.*

Variety	Average number plants per acre (000 omitted)				Percentage annual and total reduction			
	1929	1930	1931	1932	1929–30	1930–31	1931–32	1930–32
Kansas common....	834±12	429±7	203±5	59±1	49	36	78	86
Grimm............	922±13	504±6	257±4	52±2	45	48	79	89
Turkestan.........	765±10	433±9	302±4	209±3	43	29	30	51

The loss of plants in this experiment can be attributed to three factors, *viz.*, wilt, winterkilling, and a normal loss from crowding. The number of plants lost from wilt was determined by actual count in the fall, and all the plants showing wilt in the fall were assumed to have died before the next spring. This assumption was based on observations by Koehler and Jones (8), in which all plants showing top symptoms of wilt were found dead the next spring, and by the writer in which 98% of the plants showing wilt in the tops were dead by the next spring.

So far as could be determined, the literature contains no data as to the normal loss of plants due to crowding. However, it is common observation that alfalfa stands gradually thin out as fields become older. From data obtained in this experiment and recorded in Table 4, this loss was approximated for Turkestan. The total loss of plants for the Turkestan was determined from stand counts made annually. The loss due to wilt was ascertained by examining the roots of the plants. The loss due to winterkilling was based on the comparison of protected and unprotected plats having otherwise similar treatment. Any additional loss is regarded as due to crowding.

TABLE 4.—*Percentage loss of Turkestan plants from wilt, winterkilling and crowding.*

Year	Total loss of plants %	Percentage loss due to		
		Wilt	Winterkilling	Crowding
1929–30..........	43.4	0.0	2.4	41.0
1930–31..........	31.9	5.6	2.2	24.1
1931–32..........	30.9	4.9	5.3	20.7

In view of the known hardiness of Turkestan and the amount of protection provided in the protected plats, it seems reasonable to assume that very limited losses from winterkilling occurred in those plats and that the loss, except from wilt, should be attributed primarily to crowding. If this estimated percentage loss from crowding is applied to the other varieties, comparisons of the loss of plants from the three factors may be approximated, as shown in Table 5.

TABLE 5.—*Average number and percentage loss of plants due to crowding, wilt, and winterkilling.*

Variety	Number of plants per acre*	Number of plants lost per acre*	Plants lost from*			Percentage of loss due to		
			Crowding	Wilt	Winterkilling	Crowding	Wilt	Winterkilling
			1929–30					
Kansas common.....	834	405	341	0	64	84	0	16
Grimm.....	922	418	378	0	40	90	0	10
Turkestan..	765	332	313	0	19	94	0	6
			1930–31					
Kansas common.....	429	226	102	108	16	45	48	7
Grimm.....	504	247	121	124	2	49	50	1
Turkestan..	433	131	103	29	0	79	22	0
			1931–32					
Kansas common.....	203	151	41	37	73	27	25	48
Grimm.....	257	205	51	51	98	25	27	48
Turkestan..	302	93	60	17	16	64	18	18

*000 omitted.

The varietal comparison shows Turkestan to be more wilt and cold resistant than the Grimm or Kansas common. The losses from crowding are probably somewhat proportional to the thickness of the stand in which case the thinner stand of Turkestan in this experiment would tend to minimize the difference in winterkilling between Turkestan and the other two varieties.

The data in Table 2 show a material loss of plants to have occurred where the plats were not protected through the winter. This agrees with earlier observations by Moore and Graber (9), Arny (1), and others. The effect of this protection on the number of plants in the spring of each year and the percentage reduction are shown in Table 6.

TABLE 6.—*The effect of winter protection on alfalfa stands.*

Protected or exposed	Average number of plants per acre*			Percentage loss of plants	
	1930	1931	1932	1930–31	1931–32
		Kansas common			
Protected.....	460	281	91	38.9	67.6
Exposed......	455	286	45	37.1	84.2
		Grimm			
Protected.....	508	276	91	45.6	67.0
Exposed......	504	240	39	52.3	83.7
		Turkestan			
Protected.....	469	320	228	31.1	28.7
Exposed......	459	306	202	33.3	33.9

*000 omitted.

A higher average percentage loss of plants occurred in the exposed than in the protected plats except in the Kansas common in 1930–31, which was due, in part at least, to plat 1 being damaged by rodents. The difference in the protected and unprotected plats of Turkestan was slight, while in the Kansas common and Grimm it was quite significant.

From wilt counts made each fall it was evident no correlation existed between winter protection and wilt infection. In 1930–31 the counts showed an average of 2.3% more wilt-infected plants in the unprotected plats; but in 1931–32, 0.8% more in the protected, neither of which was a significant difference. The differences in varietal resistance to wilt were very striking with 5 to 6% infection in the Turkestan and 20 to 35% in the Kansas common and Grimm.

The weather conditions during the three winters this experiment was in progress were varied. In 1929–30 the lowest temperature recorded was —21° F, while in 1930–31 the winter was very mild throughout with a minimum temperature of 3° F. The winter of 1931–32 was approximately normal. During each of the three springs, late spring freezes occurred after growth had started, causing the top growth to be entirely killed.

From the data presented in Table 7 it is evident that the length of the fall growing period is a factor in maintaining stands. The 40-day growing period with the growth remaining on for winter protection gave the best results with the other treatments gradually decreasing in beneficial effect as the length of the fall growing period decreased. The most severe treatments were the five bud stage cuttings given plats 12 and 27 and the clipping after the third cutting on plats 14 and 29.

TABLE 7.—*The relation of the fall growing period to the number of plants surviving.*

Cutting treatment*					Plat Nos.	No. days in growing period after last cutting	Number of plants per acre (000 omitted) at end of experiment		
1st	2d	3d	4th	5th			Kansas common	Grimm	Turkestan
FB	FB				4, 19†	80	97	95	233
FB	FB				5, 20	80	48	54	199
FB	FB	Sept. 1			6, 21†	40	104	104	222
FB	FB	Sept. 1			7, 22	40	46	40	188
FB	FB	Sept. 15			9, 24†	25	88	89	217
FB	FB	Sept. 15			10, 25	25	44	36	213
FB	FB	Oct. 1			10, 26	10	75	50	194
B	B	B	B	B	12, 27	0	26	15	168
FB	FB	Sept. 1	Clipped‡		14, 29	0	24	14	180
B	FB	FB	FB		3, 18 8, 23 13, 28	0	43	33	224

*See Table 1 for meaning of symbols.

†Plats having winter protection.

‡Clipped after the third cutting to keep down all top growth.

Observations each spring indicated fewer live shoots on the plants in the unprotected than on those in the protected plats. A count made in the spring of 1932 gave an average of nine live shoots per plant on the protected compared to seven on the unprotected plats. This difference, while not large for one plant, when considered on the acre basis with the number of plants, would make an appreciable difference in the hay yield.

DISCUSSION OF RESULTS

A discussion of the results of this experiment may be simplified by presenting a tabular summary as has been done in Table 8. When an alfalfa stand falls below a certain number of plants per acre for a given region, it can no longer produce a maximum yield. This number is problematic as no data on minimum stands for maximum yields at the different ages are available at this time.

It is generally recognized that the number of plants decrease each year and the surviving plants become larger, thereby tending to maintain a maximum yield. In Table 8 are presented data relative to the number of plants per acre surviving at the end of this experiment in each variety. The lowest number of plants in any treatment in the Turkestan was 168,000 per acre and from all appearances the stand was perfect, or 100%. In the Kansas common and Grimm the highest average number of plants for any treatment was 104,000 plants per acre on plats 6 and 21. Although the stand was good, it could not be rated at 100%.

In order to have a uniform basis for comparison between stands following the different treatments, 150,000 plants per acre is considered a perfect stand in 3-year-old alfalfa and rated at 100% in Table 8. It will be noted that Kansas common and Grimm in plats 6 and 21 maintained a 70% stand and that the Turkestan in the same plat showed a 148% stand. The survival figures in this table are low for Kansas common and Grimm, indicating that these two varieties were either not wilt resistant or not winter-hardy or both under the conditions of this experiment. The differences in stand for these two varieties at the close of the experiment are significant for certain of the treatments and indicate that the more favorable treatments will aid in maintaining stands of alfalfa.

SUMMARY

A review of earlier literature on the cutting treatments of alfalfa indicates that time of cutting, stage of bloom at which cutting was done, winterkilling, and diseases are important factors in reducing stands of alfalfa.

More recent experiments indicate varietal differences in respect to resistance to cold and wilt of Turkestan 2674, Kansas common, and Grimm alfalfas.

Twentieth acre plats, each of which crossed areas seeded to Kansas common, Grimm, and Turkestan, were employed in this study. The field was seeded in the fall of 1928 and the plats established in the summer of 1929.

TABLE 8.—*Average number of plants per acre and percentage of normal stand surviving at the end of the experiment.*

Treatment*	Winter protection†	Plat Nos.	Number of plants per acre (000 omitted)			Percentage normal 3-year-old stand‡		
			Kansas common	Grimm	Turkestan	Kansas common	Grimm	Turkestan
1/10 B	P	1–16	76	76	238	51	51	159
1/10 B	E	2–17	41	24	209	28	16	139
B-FB-FB-FB		3–18	34	30	239	23	20	159
FB-FB	P	4–19	97	95	233	65	64	155
FB-FB	E	5–20	48	54	199	32	36	133
FB-FB Sept. 1	P	6–21	104	104	222	70	70	148
FB-FB Sept. 1	E	7–22	46	40	188	31	27	125
B-FB-FB-FB		8–23	48	43	235	32	29	157
FB-FB Sept. 15	P	9–24	88	89	217	59	60	145
FB-FB Sept. 15	E	10–25	44	36	213	30	24	142
FB-FB Oct. 1		11–26	75	50	194	50	33	129
B-B-B-B-B		12–27	26	15	168	18	10	112
B-FB-FB-FB		13–28	40	26	195	27	18	130
FB-FB Sept. 1, clipped		14–29	24	14	180	16	9	120
FB seed		15–30	92	93	206	62	62	137
P.E. of the mean for duplicate plats			±4	±6	±11			

*See Table 1 for meaning of symbols.

†P = Protected; E = Unprotected.

‡One hundred fifty thousand plants equal 100% stand.

The loss of alfalfa plants is attributed to three causes in this experiment, *viz.*, normal loss from crowding, bacterial wilt, and winterkilling.

The normal loss of plants from crowding becomes less each year as the stands become thinner.

Winter protection aided materially in maintaining the stands of Kansas common and Grimm and only slightly in the Turkestan, the most cold resistant of the three varieties.

The amount of bacterial wilt found in the plats was not affected by winter protection.

The protection afforded by a 40-day growing period after the last cutting was removed aided in maintaining the stands of alfalfa.

Cutting alfalfa in the bud stage throughout the season or keeping it clipped through the fall growing season brought about depletion in the stands more rapidly than the other treatments.

Turkestan proved to be more wilt and cold resistant and was able to withstand the more severe treatments better than either the Kansas common or Grimm.

LITERATURE CITED

1. ARNY, A. C. Alfalfa aids progress in Minnesota. Minn. Agr. Exp. Sta. Spec. Bul. 104: 29. 1926.
2. BENNETT, R. L. Alfalfa. Ark. Agr. Exp. Sta. Bul. 75: 127. 1902.
3. COTRELL, H. M. Growing alfalfa in Kansas. Kan. Agr. Exp. Sta. Bul. 114: 65. 1902.
4. HAYES, H. K. Controlling experimental error in nursery trials. Jour. Amer. Soc. Agron., 15: 177–192. 1923.
5. JANSEN, GEORGE. The relationship of organic root reserves and other factors in the permanency of alfalfa stands. Jour. Amer. Soc. Agron., 21: 895–911. 1929.
6. JONES, F. R., AND WIEMER, J. L. Bacterial wilt and winter injury of alfalfa. U. S. D. A. Cir. 39: 6. 1928.
7. KIESSELBACH, T. A., AND ANDERSON, ARTHUR. Alfalfa investigations. Nebr. Agr. Exp. Sta. Res. Bul. 36: 54–68. 1926.
8. KOEHLER, BENJAMIN, AND JONES, FRED R. Alfalfa wilt as influenced by soil temperature and soil moisture. Ill. Agr. Exp. Sta. Bul. 378: 44. 1932.
9. MOORE, R. A., AND GRABER, L. F. Alfalfa in Wisconsin. Wis. Agr. Exp. Sta. Bul. 308: 25, 31. 1919.
10. PELTIER, G. L., AND TYSDAL, H. M. The relative susceptibility of alfalfas to wilt and cold. Nebr. Agr. Exp. Sta. Res. Bul. 52: 1–15. 1930.
11. ————, ————. Hardiness studies with two-year-old alfalfa plants. Jour. Agr. Res., 43: 931–955. 1931.
12. SALMON, S. C. The reaction of alfalfa varieties to bacterial wilt. Jour. Amer. Soc. Agron., 22: 802–810. 1930.
13. ————, *et al.* Experiments relating to the time of cutting alfalfa. Kan. Agr. Exp. Sta. Tech. Bul. 15: 9–29. 1925.
14. WILLIAMS, C. G., AND KYLE, C. H. Alfalfa in Ohio. Ohio Agr. Exp. Sta. Bul. 181: 133. 1907.

SEED CORN TREATMENTS IN ARKANSAS[1]

C. K. McCLELLAND AND V. H. YOUNG[2]

Dust treatments for seed corn are more common in the northerly parts of the corn belt, where noticeable improvement in stand and yield and in freedom from seed-borne diseases often results. Especially favorable results have been obtained with seed treatments on early-planted corn which often rots in the cool, water-logged soil before it can germinate. Much of the value from dust treatments seems to result from the control of seedling blights caused by *Diplodia zeae*, *Gibberella saubinettii*, and other weak parasites. Reddy, Holbert, and Erwin (1),[3] Melhus, Reddy, Raleigh, and Burnett (2), Holbert, Reddy and Koehler (3), Reddy and Holbert (4), and Raleigh (5) reported good results especially with early-planted corn but also with late-planted corn during warm wet weather. In Nebraska, Kiesselbach (6, 7) and Kiesselbach and Culbertson (8) report that benefits from the use of dust treatments for seed corn have been less pronounced and the statement is made by Kiesselbach and Culbertson (8) that, "Seed corn selected by ordinary farm methods and secured directly from the growers has not responded significantly, on an average, to seed treatment when planted under field conditions." Wedgeworth, *et al.* (9) in Mississippi found little or no benefit from organic mercury treatments for seed corn where precautions were taken to select sound ears for seed.

Observations in northwest Arkansas, indicate that the diseases caused by *D. zeae* and *G. saubinettii* are of much less importance in Arkansas than in many parts of the main corn belt. However, since dusts for seed corn treatment are on sale and are being used by farmers in Arkansas to a very limited extent, it seemed advisable to ascertain whether or not the use of such treatments should be recommended. No attempt was made to select diseased corn seed for the experimental work, but sound seed similar to that commonly used by farmers was taken. The experimental work was carried out at the University Farm at Fayetteville on silt loam soil of rather low fertility. Seed treatments were made by agitating the seed and dust in a closed container until all seeds were thoroughly coated with the dust. Seed was planted by hand at the rate of two kernels per hill and, after stand counts had been obtained, the plants were thinned to one plant per hill.

1928 METHODS AND RESULTS

Neal's Paymaster corn seed was treated with Bayer Dipdust and Semesan Jr. at the rate of 3 ounces per bushel. Each plat consisted of 21 rows 132 feet long and was equivalent to 0.233 acre. There were four replications of each treatment and five checks, making a total of

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[2] Assistant Agronomist and Plant Pathologist respectively.

[3] Reference by number is to "Literature Cited," p. 195.

13 plats. Seed was planted May 7, a medium planting date for the given locality. The land was cultivated according to standard practices at University Farm, and on June 2, 1928, the data on germination were obtained by counting the number of plants in 10 rows from each plat. Table 1 gives the data on germination and yield of corn as influenced by dust seed treatments in 1928.

TABLE 1.—*Effects of seed treatments on germination and yield of corn, 1928.*

	Check plats, no seed treatments	Seed treated with	
		Dipdust	Semesan Jr.
Ave. No. plants per row	131.3±.712	129.3± .78	120.0± .991
Differences		—2.0±1.05	—11.3±1.22*
Mean yield, bu. per acre	59.4±.73	61.33± .77	58.97±1.456
Differences		1.93±1.02	—.43±1.63

*Significant differences.

As will be noted from Table 1, the effect of Dipdust on the stand was so slight as to be of no significance. On the other hand, the first stands in the plats treated with Semesan Jr. were significantly lower than those of the checks. Yield records were obtained by weighing the corn obtained from every three rows, thus giving seven weights per plat. Much confidence can be placed in the insignificance of the differences in yield, the probable errors having been determined from 28 three-row plats which had treated seed and from 35 such plats from non-treated seed.

1929 METHODS AND RESULTS

In 1929, Sterocide, the active principal of which is said to be mercury furfuramide, was substituted for Dipdust. This was applied at the rate of 2 ounces per bushel. Since work in the northern states had emphasized the fact that seed treatments may protect seed corn from decay during periods of cold weather when germination is retarded and certain cold-tolerating fungi are active, it was decided to test the effect of seed treatments on early, medium, and late plantings. Paymaster corn was again used. The dates of planting were April 25, May 20, and June 15, the time interval being about 25 days. Seed was treated in the manner previously described. Three replications of the treatments were made in each planting, there being 10 rows per plat.

Counts of plants were again made to note the effect of the dust treatments upon the germination. Later the corn was thinned to one stalk per hill. The results are summarized in Table 2.

The results show significant and consistent increases in the number of plants in the early plantings from use of the treatments and consistent and significant decreases from their use in the late plantings. At the medium date the results were variable, Sterocide giving significant increase in number of plants and Semesan Jr. no marked difference.

TABLE 2.—*Effects of seed treatments on germination and yield of corn, 1929.*

	Check plats, no seed treatment	Seed treated with	
		Sterocide	Semesan Jr.
	Planted April 25		
Ave. No. plants per row	98.73±.428	105.87±.419	107.6 ±.353
Differences*		7.14±.6†	8.87±.55†
Mean yield, bu. per acre	12.4 ±.774	19.17±.524	16.03±.622
Differences*		6.77±.93†	3.63±.99†
	Planted May 20		
Ave. No. plants per row	115.6 ±.342	123.93±.292	115.27±.585
Differences*		8.33±.45†	—.33±.67
Mean yield, bu. per acre	14.62±.456	15.76±.719	15.27±.814
Differences*		1.14±.85	.65±.93
	Planted June 15		
Ave. No. plants per row	128.93±.352	125.4 ±.448	125.8 ±.262
Differences*		—3.53±.57†	—3.13±.44†
Mean yield, bu. per acre	10.16±.482	10.23±.442	8.81±.4
Differences*		.07±.65	—1.35±.62

*Differences in comparison with check.
†Significant differences.

Yields in 1929 are shown to be much less than in 1928. Just as the treatments of seed in early plantings seemed beneficial to the stand, so the resulting yields showed significant increases. In the medium and later plantings no differences in yield were significant.

1930 RESULTS

In 1930 seed treatments with Semesan Jr. and Sterocide were again made. The corn was planted April 16, May 7, and May 25, planting two seeds per hill. After counts were made, the plants were thinned to one plant per hill. Table 3 gives the plant counts in average number per row for the several dates and treatments, their errors and differences, and also the yields per acre on the several plats.

In the early planting, contrary to expectation, and very much contrary to results of 1929, the number of plants was significantly greater where no seed treatment was given. In the early May planting no treatment and treatment with the Semesan Jr. dust gave a better germination count than was obtained from seeds on which Sterocide was used though the difference between the Sterocide and Semesan Jr. treatments attained no significance. In the late May planting, contrary again to results of 1929, the seed not treated gave the lowest average number of plants per row, but the differences amount to nothing when the probable error is taken into consideration.

On account of drouth and a very unfavorable season for the corn crop in 1930, any statistical constants which might be calculated from the yield data would be of little value from the seed treatment standpoint.

TABLE 3.—*Effect of seed treatments on germination and yield of corn, 1930.*

	Check plats, no seed treatment	Seed treated with	
		Sterocide	Semesan Jr.
	Planted April 16		
Ave. No. plants per row*	138.7± .788	129.8± .833	131 ±1.179
Differences		—8.9±1.146†	—7.7±1.418†
Ave. yield per 10 rows, lbs.	66.7	88.3	85.5
	Planted May 7		
Ave. No. plants per row	117.6±1.501	109.6±1.104	116.6± .890
Differences		—.8±1.863†	—1 ±1.745
Ave. yield per 10 rows, lbs.	12.9	15.7	9.3
	Planted May 25		
Ave. No. plants per row	109.4±1.86	116.6±1.389	114.2±1.408
Differences		7.2±2.321†	4.8±2.322
Ave. yield per 10 rows, lbs.	79	100.3	95.1
Ave. No. plants all rows	121.9	118.7	120.6
Ave. yield all plats, bu. per acre	6.8	8.8	8.2

*Averages of 24 to 30 rows.
†Significant differences.

THE 1932 EXPERIMENTS

Another test was undertaken in 1932. Sterocide and Semesan Jr. were again used and also Merko and Dubay 1100. The normal number of hills per row was 72 and two kernels were planted in each hill. The number of plants coming up and also the stands after thinning were recorded for each row. The means and errors for each treatment and each date were determined and the "mean differences" from check of each treatment. In Table 4 the ranges of means along with the mean differences and errors are given.

On the April 18 planting, no effect of seed treatment on germination, ultimate stand, or yield was obtained from Merko, Dubay 1100, or Sterocide. Semesan Jr. apparently caused some reduction in germination and stand, but there was no reduction in yield. On the May 5 planting, significant increases in germination and stand were obtained on the Dubay 1100 and Sterocide plats and an increased yield on the Merko and Dubay 1100 plats.

On the May 21 planting, there were no significant differences in the germination. The stand was better on the Sterocide plat and gains in yield were obtained on all plats except where the seed had been treated with Semesan Jr.

In two cases (with Dubay 1100 on May 5 and Sterocide on May 21) increases in yields correspond with an increase in ultimate stand, only the former, however, corresponding with a difference in germination, the gain in yield amounting to 6.8 bushels per acre. The other gains in yields might be attributed to soil variations.

The effect of seed treatments might be felt in two ways, *viz.*, an increased vigor or rapid growth which might be reflected in the yield and a better stand which also might result in better yields. The above table shows that in only two cases did significant increases in

TABLE 4.—*Germination, stands, and yields of corn as affected by seed treatments, 1932.*

Treatment	Mean differences between treatments and checks		
	Seedlings per row	Stand after thinning	Lbs. corn per row
	Planted April 18		
Range of means	110–122	63–67	27.2–30.5
Merko	— 2±2.78	—1± .86	1.4±1.35
Dubay 1100	1±2.94	—1± .95	—1.9± .92
Sterocide	— 4±2.85	—2± .86	0.1± .81
Semesan Jr	—11±3.09*	—4±1.25*	1.1± .94
	Planted May 5		
Range of means	97–108	61–69	26.1–34.9
Merko	—3±1.91	—1± .99	7.9± 1*
Dubay 1100	8±1.91*	7± .78*	5.3± 1.22*
Sterocide	6±2.02*	6± .75*	3.0± 1.40
Semesan Jr	3±2.07	2± .83	—0.9± 1.34
	Planted May 21		
Range of means	115–122	67–71	28.7–32.7
Merko	—4±2.82	Even	4.4±1.06*
Dubay 1100	—3±2.32	3±1.33	3.3± .97*
Sterocide	3±2.75	4±1.26*	4.0±1.03*
Semesan Jr	3±2.73	3±1.39	1.0±1.06

*Significant differences.

yields follow significant differences in ultimate stand. A summary of the four tests is presented in Table 5.

TEMPERATURE AND RAINFALL

Table 6 gives the average monthly temperatures and rainfall for the different planting dates and also the same data for the weeks beginning on the respective dates. A study of these figures reveals very few departures from what would be termed normal conditions.

The rainfall was unusually heavy in the month preceding the 1928 planting, but temperatures for the month of planting were not abnormal. In 1929, temperatures for the month of April and for the week of planting were somewhat low. On the April planting both Sterocide and Semesan Jr. gave increases in stand and yield. In 1930 and in 1932, when temperatures were higher in April, there was a reduction in first stands from both treatments. There is at best only a slight indication that some benefit would accrue from such seed treatments in cold weather.

SUMMARY AND CONCLUSIONS

A study was made over a 4-year period of the effects of various dust treatments of seed on germination and yield of Paymaster corn. In 1928, only a single planting was made. Treatments were with Dipdust and Semesan Jr. No significant gains or losses in either germination or yield attended the use of Dipdust. With Semesan Jr. there was some reduction in the number of seedlings secured but no difference in yield.

TABLE 5.—*Summary of four years study of effect of seed corn treatments with various chemicals; differences* in first stand, ultimate stand (1932), and yields.*

	Dipdust	Dubay 1100	Sterocide	Semesan Jr.
		1928		
May 8, 1st stand.....	—2 ±1.05	———	———	—11.3 ±1.22†
Yield, bu............	1.93±1.02	———	———	— .43±1.63
		1929		
Apr. 25, 1st stand.....	———	———	7.14± .6†	8.87± .55†
Yield, bu............	———	———	6.77± .93†	3.63± .99†
May 20, 1st stand....	———	———	8.33± .45†	— 0.33± .67
Yield, bu............	———	———	1.14± .85	0.65± .93
June 15, 1st stand....	———	———	—3.53± .57†	— 3.13± .44†
Yield, bu............	———	———	0.07± .65	— 1.35± .62
		1930		
Apr. 16, 1st stand.....	———	———	—8.9 ±1.15†	— 7.7 ±1.42†
Yield, lbs............	———	———	21.6	18.8
May 7, 1st stand.....	———	———	—8.0 ±1.86†	— 1.0 ±1.75
Yield, lbs............	———	———	2.8	—3.6
May 25, 1st stand....	———	———	7.2 ±2.32†	4.8 ±2.32
Yield, lbs............	———	———	21.3	16.1
Ave. yields, bu.......	———	———	8.8	8.2
		1932‡		
Apr. 18, 1st stand.....	—2.0 ±2.78	1.0 ±2.94	—4.0 ±2.85	—11.0 ±3.09†
Ultimate stand.......	—1.0 ± .86	—1.0 ± .95	—2.0 ± .86	— 4.0 ±1.25†
Yield, bu............	1.4 ±1.35	—1.9 ± .92	0.1 ± .81	1.1 ± .94
May 5, 1st stand.....	—3.0 ±1.91	8.0 ±1.91†	6.0 ±2.02†	3.0 ±2.07
Ultimate stand.......	—1.0 ± .99	7.0 ± .78†	6.0 ± .75†	2.0 ± .83
Yield, bu............	7.9 ±1.00†	5.3 ±1.22†	3.0 ±1.40	— 0.9 ±1.34
May 21, 1st stand....	—4.0 ±2.82	—3.0 ±2.32	3.0 ±2.75	3.0 ±2.73
Ultimate stand.......	Even	3.0 ±1.33	4.0 ±1.26†	3.0 ±1.39
Yield, bu............	4.4 ±1.06†	3.3 ± .97†	4.0 ±1.09†	1.0 ±1.06

*Differences are between counts of plants or yields on plats having treated and those having untreated seed.

†Significant differences. Yields for 1930 abnormally low; not treated statistically.

‡Merko used in place of Dipdust in 1932.

In 1929, Sterocide and Semesan Jr. were used and plantings made April 25, May 20, and June 15. With the early planting each gave significant increase in the number of seedlings and in yields. With the

TABLE 6.—*Average temperatures and rainfall of planting seasons.*

	Average monthly temperatures			Rainfall in inches		
	April	May	June	April	May	June
1928..........	54.4	66.0	69.2	10.56	4.56	8.90
1929..........	61.0	63.7	76.2	6.67	7.50	6.96
1930..........	63.1	65.1	72.2	2.83	6.88	4.00
1932..........	62.0	67.5	76.0	2.28	1.71	8.65
	Average temperatures and rainfall for week following each planting*					
1928..........	....	66.36	....	....	0.08	....
1929..........	57.3	62.4	75.6	0.72	1.03	0.40
1930..........	61.8	66.43	62.36	1.27	1.32	0.00
1932..........	66.43	66.8	73.36	0.32	0.30	1.31

*The dates of respective plantings are given in Table 5.

intermediate planting the only effect was a slight increase in number of seedlings from use of Sterocide. In the late planting, each treatment caused significant decreases in number of seedlings with no resultant effect on yield.

In 1930, Sterocide and Semesan Jr. were again used, plantings being made April 16, May 7, and May 25. The year of 1930 was a very trying year on account of a prolonged drought. Contrary to results of 1929 both treatments caused significant decreases in number of seedlings in the early planting. Sterocide gave a decrease again in number in the intermediate planting, but in the late planting there was a significant increase. The early plantings yielded much better than the later, but all yields were abnormally low and statistical treatment of yields was not attempted.

In 1932, Merko, Dubay 1100, Sterocide, and Semesan Jr. were used on plantings made April 18, May 5, and May 21. In addition to original counts of seedlings, later counts were made after thinning to one stalk. Semesan Jr. caused reduced number of seedlings and reduction in ultimate stands, but no difference in yield in the early planting. Sterocide gave an increase in seedlings in the intermediate plantings and improved ultimate stands and yields in both intermediate and late plantings. Dubay 1100 gave increase in number of seedlings and improved stand in the intermediate planting and improved yields in this and also in the late planting. Merko also gave increased yields in the two later plantings, but had no significant effect on first or ultimate stands.

A study of monthly and weekly temperatures of the planting dates, and also of the rainfall, failed to reveal any explanation for the variable results obtained.

Except in 1929, Semesan Jr., caused significant reductions in first stands in all early plantings.

The conclusion must be drawn that, under the conditions of these tests, no assured benefit can be obtained as a result of dust treatments of seed corn.

LITERATURE CITED

1. Reddy, C. S., Holbert, J. R., and Erwin, A. T. Seed treatments for sweet-corn diseases. Jour. Agr. Res., 33: 769–779. 1926.
2. Melhus, I. E., Reddy, C. S., Raleigh, W. P., and Burnett, L. C. Seed treatment for corn diseases. Iowa Agr. Exp. Sta. Circ. 108. 1928.
3. Holbert, J. R., Reddy, C. S., and Koehler, B. Chemical-dust seed treatments for dent corn. U. S. D. A. Circ. 34. 1928.
4. Reddy, C. S., and Holbert, J. R. Further experiments with seed treatments for sweet-corn diseases. Jour. Agr. Res., 36: 237–247. 1928.
5. Raleigh, W. P. Infection studies of *Diplodia zeae* (Schw.) Lev. and control of seedling blights of corn. Iowa Agr. Exp. Sta. Res. Bul. 124: 96–121. 1930.
6. Kiesselbach, T. A. Field experiments with seed corn treatments and crop stimulants. Nebr. Agr. Exp. Sta. Bul. 218. 1927.
7. ————. Field tests with treated seed corn. Jour. Agr. Res., 40: 169–189. 1930.
8. ———— and Culbertson, J. O. An analysis of the effects of Diplodia infection and treatment of seed corn. Jour Agr. Res., 42: 723–749. 1931.
9. Wedgeworth, H. H., Ferris, E. B., Wallace, H. F., and York, H. A. Corn seed treatment experiments. Miss. Agr. Exp. Sta. Circ. 81. 1928.

THE LOSS IN YIELD THAT MAY BE EXPECTED FROM PLANTING SECOND GENERATION DOUBLE-CROSSED SEED CORN[1]

FREDERICK D. RICHEY, G. H. STRINGFIELD, AND GEORGE F. SPRAGUE[2]

Farmers have been advised generally against planting second-generation seed from corn hybrids which they have purchased or obtained in other ways. Most of this hybrid seed has been the first generation of either three-way or double crosses among selfed lines, and the advice relative to planting the progeny appears to have been based upon the theories of hybrid vigor and the demonstrated reduction in yield from the F_1 to the F_2 in single crosses rather than on experiments with three-way and double crosses as such. It accordingly seemed worth while to obtain some definite evidence on the relative yields of F_1's and F_2's and the present paper reports such data.

MATERIAL AND METHODS

Ten double crosses which were entered in the Iowa yield test in 1931 were grown in 2-row plats at the Arlington Experiment Farm, Rosslyn, Va., in the same year. Pollinations were made across the two rows of each plat and more than 30 F_2 ears of each double cross were obtained. These ears were shelled to obtain seed representative of the F_2. F_1 seed of the same double crosses was produced by hand pollinating between the parent single crosses in the same season at the same place.

The F_1 and F_2 generations were compared at the Southwestern Experiment Farm[3] of the Ohio Agricultural Experiment Station at Germantown, Ohio, in 1932. Each generation of each cross was grown in seven plats of 4 x 10 hills. Four seeds were planted in each hill with no subsequent thinning. The experiment was divided into seven series, the crosses being arranged at random within each series. The individual rows of the plats were harvested separately and the yields were computed for the entire plats and also for the two interior rows of each plat. A comparison indicated that there was some effect from competition and the data presented herein, except for marketable ears, are based on only the two interior rows.

EXPERIMENTAL DATA

The yields and other data are presented in Table 1. Yield data are for shelled corn containing 15.5% of moisture. The moisture contents and shelling data were based on 10-pound samples taken from

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[2] Principal Agronomist in Charge of Corn Investigations, Division of Cereal Crops and Diseases; Associate Agronomist, Ohio Agricultural Experiment Station and Agent, Division of Cereal Crops and Diseases; and Assistant Agronomist, Division of Cereal Crops and Diseases, respectively.

[3] The writers wish to express their appreciation to H. M. Wachter, Superintendent, for his hearty cooperation in this experiment.

TABLE 1.—*Data on the F_1 and F_2 generations of 10 double crosses grown at the Southwestern Experiment Farm of the Ohio Agricultural Experiment Station, Germantown, Ohio, in 1932.**

Pedigree	Total No. of plants		No. of days planting to silking		Dry matter in ears at harvest%		Marketable ears per 100 plants†		Unmarketable ears per 100 plants†		Acre yield			
											Bushels		Decrease	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	Bu.	%
(4-1x317)x(276x420)	449	410	69	73	71	67	97	90	3.1	10.3	87.9	68.4	19.5	22
(351x420)x(4-1x3-3)	440	421	69	73	76	70	93	83	4.9	12.7	82.2	68.1	14.1	17
(4-8x6-5)x(540xA)	434	408	71	73	71	69	102	98	2.6	6.3	82.2	62.3	19.9	24
(4-1x3-3)x(540xA)	446	414	69	74	72	70	98	91	2.1	8.0	82.0	66.7	15.3	19
(351x345)x(540xA)	445	438	72	73	71	72	100	104	5.5	6.2	78.3	69.9	8.4	11
(4-1x3-3)x(AxB)	355	414	70	69	71	73	96	95	3.1	3.6	76.6	65.7	10.9	14
(9-1x461)x(540xA)	431	430	73	73	67	66	92	95	5.3	7.3	76.0	72.0	4.0	5
(1x2)x(4-8x6-5)	412	406	72	73	67	70	94	90	3.1	8.7	73.8	66.3	7.5	10
(4-8x6-5)x(351x420)	419	410	70	73	71	69	95	85	4.4	11.5	73.2	63.3	9.9	14
(7-6x6-5)x(540xA)	497	430	73	74	71	69	98	92	6.8	10.1	73.0	61.4	11.6	16
Average	433	418	70.8	72.8	70.8	69.5	96.5	92.3	4.1	8.5	78.5	66.4	12.1	15.2

*Standard error of a difference = 4.7 bu.

†Based on 4-row plats.

each of four of the seven replications. Three open-pollinated local varieties obtained from farmers in the neighborhood and judged to be satisfactorily adapted there were grown in the same 2-acre block with the hybrids. Their acre yield averaged 65.5 bushels, with 65.2% of dry matter in the ears at harvest. The acre yields of the hybrids in the 1932 comparisons, therefore, show them to be reasonably well adapted to Ohio conditions.

The differences in favor of the F_1 generation as regards stand, earliness in time of silking, dry matter at harvest, marketable ears produced, and acre yield are fairly consistent. They are what might perhaps have been expected, except for the differences in stand, for which no reason is known.

The F_1 generation yielded more than the F_2 in each of the 10 crosses. All but one of the differences in yield exceed the standard error of such a difference (4.7 bushels), and 7 of the 10 differences exceed twice this error. The standard error (due to experiment only) for the mean decrease is 1.5 bushels so that the mean acre decrease may be placed as between 9 and 15 bushels from 1 acre. Under the conditions of this experiment the loss from using 1 bushel of F_2 seed may be estimated as around 70 bushels. Even at present ruinous prices for corn, such a gain from using F_1 seed represents a profit over the usual cost of the seed.

A comparison of the variance due to the interaction of the generations and the crosses with that due to random error shows the former to be larger with $z = 0.75$ and a 1% point of 0.41.[4] Variation in the size of the decrease obviously therefore is significant. Furthermore, the decrease tends distinctly to be larger in the higher yielding F_1 crosses. In so far as these crosses are representative, the larger decreases in the F_2 may be expected with the more productive crosses—the ones which finally get into commercial use. Doubtless this tendency may be offset in individual cases by the character of the inherent productiveness and ability to combine to advantage *inter se* of the particular inbred parent strains.

Occasional reports have come from farmers stating that excellent yields had been obtained from second generation seed which they produced and planted. There appears to be no inherent reason why good yields should not be obtained from such F_2 seed. If, for example, a double cross exceeds the best local variety by 25% in the F_1, a reduction of 20% from the F_1 to the F_2 would leave the F_2 of such a hybrid equal to the best local variety. In fact, the F_2 of only 3 of the 10 crosses in these experiments was below the average yield of 65.5 bushels of the three open-pollinated varieties. With a slightly better season in the year in which the F_2 was grown, a farmer well might think that the F_2 was just as good as or even better than the F_1. The data presented here, however, appear ample to warrant continuation of the advice against planting F_2 seed of double crosses.

SUMMARY

The acre yields of the F_2 generation of 10 double crosses among selfed lines of corn were from 4.0 to 19.9 bushels, or from 5 to 24%,

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[4] Fisher. R. A. Statistical Methods for Research Workers. Edinburgh. 1932.

less than those of the F_1 generation of the same crosses, with an average decrease of 12.1 (standard error = 1.5) bushels, or 15.2%. The value of such a loss would more than compensate for the cost of F_1 seed even at present prices (1933). Variation in the size of the decrease is highly significant statistically, the larger decreases tending to occur among the higher yielding F_1 crosses.

METHODS OF ESTIMATING THE PERFORMANCE OF DOUBLE CROSSES IN CORN[1]

MERLE T. JENKINS[2]

In a recent publication[3] it was demonstrated that inbred-variety crosses may be used efficiently for the preliminary testing of inbred lines of corn. If the lines are to be used eventually in double crosses, it is important to know whether the data from the comparison of inbred-variety crosses may be used to estimate the performance of the lines in double crosses. If so, it should be possible to eliminate entirely the laborious testing of single crosses and proceed directly from the testing of inbred-variety crosses to the testing of double crosses.

This paper presents data on four methods of estimating the performance of double crosses. Three of the methods utilize information on the single crosses of the parents and probably represent the methods of estimation in most common use. The fourth method utilizes only the information from the inbred-variety crosses of the parents.

MATERIALS AND METHODS

The crosses used for these studies were grown in a yield comparison in the season of 1930. The material included in this comparison comprised all but 2 of the 55 possible single-cross combinations among 11 inbred lines, the inbred-variety crosses of these lines, and 42 double crosses among them.

Data were taken on the acre yield and on a number of plant and ear characters. The characters studied were (1) percentage of plants with burned upper leaves, (2) height of the upper ear above the soil surface, (3) percentage of plants erect at harvest, (4) moisture content of the harvested ears, (5) shelling percentage, and (6) acre yield.

The actual performance of the double crosses for each of these characters was compared with its estimated performance using the four methods of estimation. For convenience in reference the different methods of estimation are designated A, B, C, and D. Each method utilizes information usually available in advance of the production or at least in advance of the testing of the double crosses.

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[1] The data on which this paper is based were obtained in connection with the corn improvement program at Ames, Iowa, conducted by the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, in cooperation with the Farm Crops Subsection, Iowa Agricultural Experiment Station. Journal Paper No. B 110 of the Iowa Agricultural Experiment Station. Project No. 163. Received for publication April 13, 1933.

[2] Associate Agronomist.

[3] JENKINS, MERLE T., and BRUNSON, A. M. Methods of testing inbred lines in crossbred combinations. Jour. Amer. Soc. Agron., 24: 523–530. 1932.

Methods A, B, and C utilize information from the single crosses of the parental lines, while method D utilizes information from the inbred-variety crosses of the lines. The four methods of estimation are described in detail below.

Method A.—This estimate was obtained by computing the mean of the values for any character in all of the six possible single crosses among the four inbred parents of the double cross. For example, the estimate of a given character in a double cross involving lines W, X, Y, and Z is the mean of the values for that character in the single crosses WX, WY, WZ, XY, XZ, and YZ.

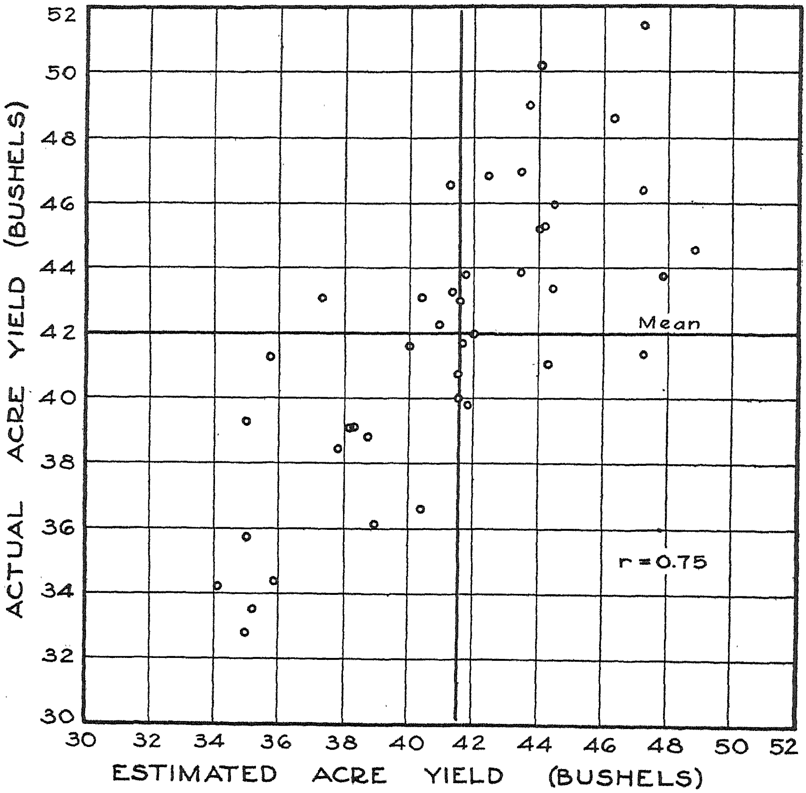

FIG. 1.—Scatter diagram of the actual acre yield of 42 double crosses and the method A estimates of their yields.

Method B.—In any double cross the genes of each of the four parental lines are united only with allelomorphs of the two lines which entered the double cross from the opposite parent. In the double cross WX x YZ, therefore, it would seem that the crosses WY, WZ, XY, and XZ better represent the hybrid combinations actually occurring than do all six of the possible combinations among these lines. In obtaining the method B estimate the two single cross parents of each double cross were excluded and the mean of the values for the remaining four of the six possible single crosses among the four inbred parents of the double cross was computed. Obviously, different estimates for double crosses involving the same parental lines but combined in an unlike manner will be obtained by this method, whereas by method A the same estimate will be obtained for all combinations of the same parental lines.

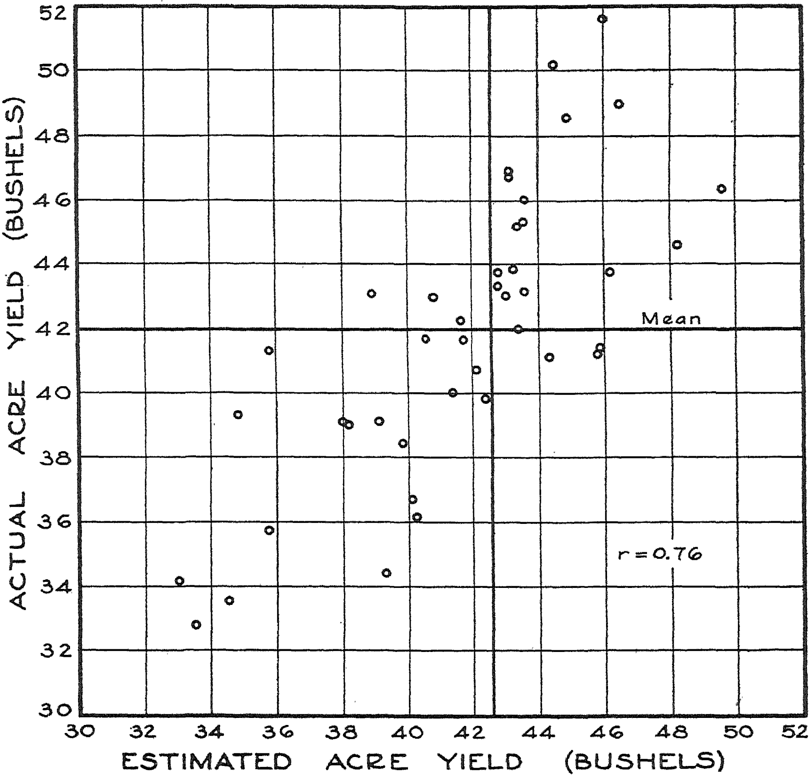

FIG. 2.—Scatter diagram of the actual acre yield of 42 double crosses and the method B estimates of their yields.

Method C.—As stated previously all but 2 of the 55 possible single crosses among 11 inbred lines were grown in the 1930 yield comparison. The mean value for each character for all of the single crosses of which each line was a parent was computed. The mean of these "means of all crosses" for the four parental lines of each double cross constituted its method C estimate.

Method D.—This estimate was obtained for each double cross by calculating the mean of the values for the inbred-variety crosses of its four parental lines.

EXPERIMENTAL RESULTS

Coefficients of correlation were computed between the actual performance of the double crosses and the estimates of their performance obtained by the four methods of estimation. These coefficients are recorded in Table 1.

TABLE 1.—*Coefficients of correlation between the performance of double crosses and the estimates of their performance as obtained by four different methods.*

Character	Method of estimation			
	A	B	C	D
Burned leaves	0.60	0.65	0.57	0.57
Ear height	0.38	0.42	0.32	0.31
Plants erect	0.77	0.70	0.75	0.64
Moisture	0.69	0.61	0.72	0.49
Shelling percentage	0.70	0.78	—0.06	0.70
Acre yield	0.75	0.76	0.73	0.61

Significant r = 0.39. (Fisher, R. A. Statistical Methods for Research Workers. London: Oliver & Boyd. Ed. 3. 1930. Table V. A.)

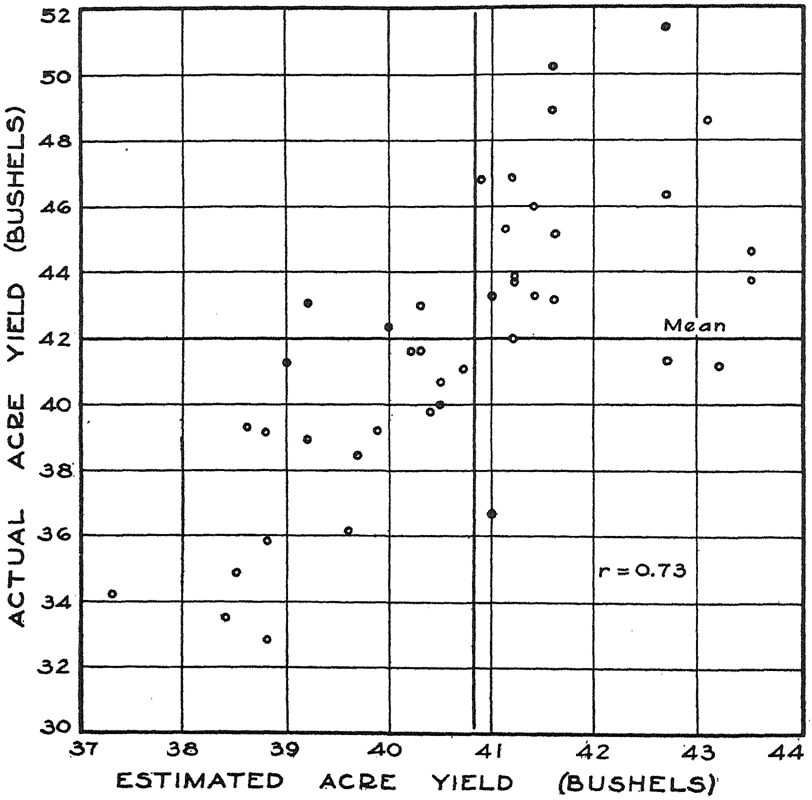

FIG. 3.—Scatter diagram of the actual acre yield of 42 double crosses and the method C estimates of their yields.

The coefficients of correlation for method D are slightly lower than for the other methods of estimation. In view of the fact, however, that this estimate requires the testing of only one inbred-variety cross for each parental line instead of the large numbers of single crosses upon which the other methods of estimation are based. it appears to have much in its favor.

The scatter diagrams of acre yield for the four methods of estimation are shown in Figs. 1 to 4, inclusive. In each figure the mean yield of the double crosses is indicated by a horizontal line at 42 bushels. A vertical line in each figure divides the estimated yields into two groups of equal size.

Assuming that in each case the 50% of the double crosses with the highest estimated yield had been produced for testing, they would be represented by the dots to the right of the heavy vertical line in each figure. The dots in the upper left quarter of each diagram would represent double crosses above the average in yielding ability which would not have been produced for test. The number of dots in this quarter for the different methods of estimation are as follows: Method A (Fig. 1)—5, method B (Fig. 2)—3, method C (Fig. 3)—3, and method D (Fig. 4)—5. The numbers in each case are small and the differences among them cannot be considered significant.

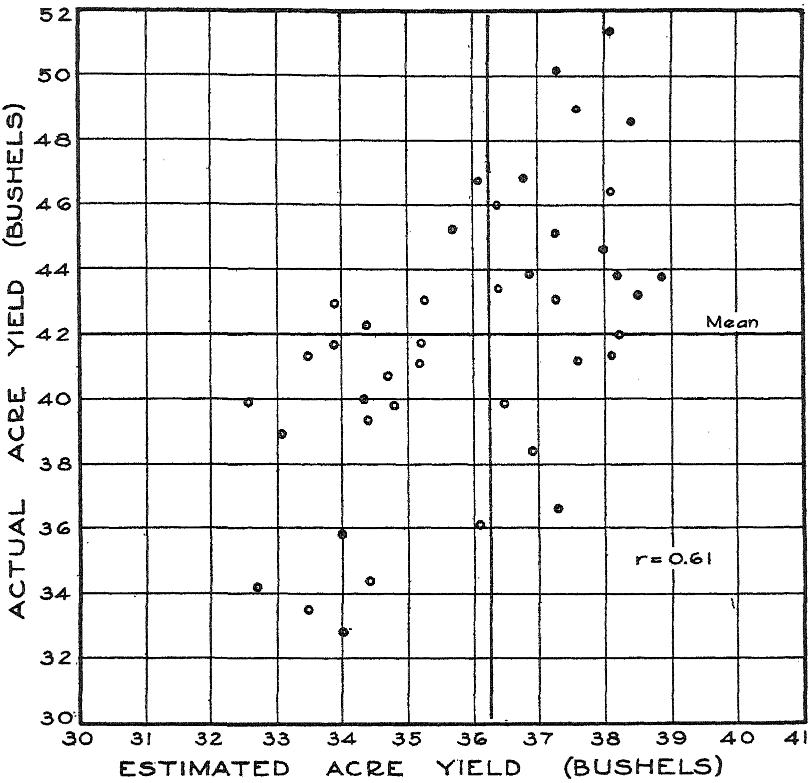

FIG. 4.—Scatter diagram of the actual acre yield of 42 double crosses and the method D estimates of their yields.

Each method of estimation includes the four highest yielding double crosses within the 50% with the highest estimated yields. Likewise, by each method of estimation, the upper 60% of the estimated yields includes all of the upper one-third of the observed yields. If the 60% of the double cross combinations having the highest estimated yield were tested, therefore, it would appear that there was little danger of losing any really superior material.

Method D gave a somewhat wider scatter of the estimated yields than the other methods of estimation. The scatter does not appear to be enough greater, however, materially to reduce the value of this method of estimation as compared with the other methods.

DISCUSSION

Data have been accumulated over several years comparing the inbred-variety-cross method of testing inbred lines in crosses with the more common procedure of testing them in single crosses. As previously mentioned,[4] some of these data already have been published. On the basis of the accumulated data the yield comparisons of single crosses previously conducted each year at the Iowa Experiment Station were discontinued at the end of the season of 1931. Many of the inbred lines in the possession of the Station have now been compared in inbred-variety crosses for three seasons. Lines that were obviously undesirable were discarded after the first year's test. A few additional lines will be discarded this season on the basis of the 3-year data. A 5-year comparison should give a reasonably reliable classification of the remaining lines and this classification will be valuable in estimating the performance of double crosses produced from these lines.

The inbred-variety-cross method of comparing inbred lines in crosses would seem to have many advantages. Probably the most important of these is that of permitting the inclusion of all lines in the yield comparisons each season. At the end of a 5-year testing period the data from comparisons in which each line is tested each year should be definitely superior to data in which the individual lines have had extensive trials in individual seasons only.

The data presented here indicate that the data from inbred-variety crosses are nearly as reliable for estimating the yields of double crosses within a single season as are the more extensive data from the comparison of the necessarily larger numbers of single crosses. If the data for a single season are nearly as reliable, it would seem that the testing method that permits the inclusion of each line each year would give the more valuable data over an extended period of testing.

SUMMARY

The actual performance of 42 double crosses was compared with the estimates of their performance obtained from information on the single crosses among their parental lines and on the inbred-variety crosses of the parental lines.

The data indicate that the information obtained from comparisons of inbred-variety crosses may be utilized to advantage in estimating the performance of double crosses among these lines.

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[4] *Op. cit.*

EARLINESS IN NORTHERN CORN AS AFFECTED BY PHOSPHATE FERTILIZERS, MANURE, AND OTHER SOIL TREATMENTS[1]

P. J. OLSON AND H. L. WALSTER[2]

Farm practices which reduce the hazard of losses due to frost are usually of economic advantage in the more northern latitudes of the United States. Fall frosts frequently injure the later varieties of corn. Phosphate fertilizers normally hasten the maturity of all crops. For recent contributions to the effect of phosphates in the maturation of crops, the reader is referred to the compilation by Hartwell (3)[3] and to the statements by Brand (1). Notable recent contributions applying to corn have been made by Salter (10) and by Truog (14). Williams (15), Musgrave and Coe (7), Blackwell and Buie (2), all working with cotton, and Hepler and Kraybill (4), working with tomatoes, have noted a maturity-retarding effect with potassium fertilizers. Schuster (11, 12), working with corn and soybeans, and Skinner and Pate (13), working with cotton, noted a maturity-advancing effect of potassium on soils notably deficient in potassium. Noll (8), working with wheat on soils on which potassium fertilizers increased yields, found that potassium fertilizers advanced the maturity of the crops.

The present study was begun to determine the extent of the advancement of maturity of corn under the soil and climatic conditions at Fargo, North Dakota.

The average frost-free season at Fargo is 135 days (May 12 to September 24), according to observations at the U. S. Weather Bureau observatory at Moorhead, Minnesota, about 2 miles from the experimental fields used in the trials reported upon in this paper. The first killing frost in the autumn has occurred earlier than September 24, 18 times in the 50 years of observation. The average monthly temperatures for the corn growing months in the 50-year period have been as follows: May, 54.1° F; June, 64.3° F; July, 68.7° F; August, 66.6° F; and September, 57.5° F. Of the 8 years of these trials the corn growing months were markedly cooler than the average in 1924 and 1927 and markedly warmer than the average in 1929, 1930, and 1932. August and September temperatures were well above the average in 1925. The seasons of 1926 and 1928 were nearly average with respect to temperature.

The soil used in these trials is a Fargo clay. The average chemical composition (5) of six samples of Fargo clay from Cass County, North Dakota, the county in which these trials were conducted, is set forth in Table 1.

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[1] Contribution from the Department of Agronomy, North Dakota Agricultural Experiment Station, Fargo, N. Dak. Published with the approval of the Director. Received for publication April 24, 1933.

[2] Assistant Agronomist and Agronomist, respectively.

[3] Reference by number is to "Literature Cited", p 212.

TABLE 1.—*Average chemical composition of six samples of Fargo clay from Cass County, N. Dak.*

Soil constituent	Surface, 0–7 in., %	Subsurface, 7–20 in., %	Subsoil, 20–40 in., %
Total nitrogen	0.324	0.159	0.095
Total phosphorus	0.0657	0.0560	0.0560
Total potassium	1.715	——*	——*
Total calcium	1.36	2.82	4.91
Total magnesium	1.089	1.446	1.766
Total sulfur	0.0643	0.0420	0.0648
Organic carbon	4.060	1.8960	1.0660
Carbonate carbon	0.079	0.672	1.510

*Not determined.

The following outline sets forth the plan of soil treatment and the serial arrangement of the plats on Series I:[4]

Treatment*	Character and quantity of fertilizer applied per acre per rotation
None	
Manure	Fresh stable manure, 9–12 tons
Manure+P	Fresh stable manure, 9–12 tons, treble superphosphate containing 44% P_2O_5, 150 pounds
Manure+P+L	Manure and phosphate as above and 1,000 pounds ground limestone containing about 85% $CaCO_3$ and 15% $MgCO_3$
None	
Manure	Same as corresponding item above
Manure+P	Same as corresponding item above
Manure+P+L	Same as corresponding item above
Manure+P+L+K	Manure, phosphate, and limestone same as 4 and 8; 120 pounds of sulfate of potash

*Abbreviations in this and subsequent tables are as follows: P=superphosphate; L=ground limestone; K=sulfate of potash.

All soil amendments are applied once during a 4-year rotation period. The rotation consists of corn, wheat, oats, and clover in the order named. Corn is the first crop to follow each soil treatment. During the earlier years of the experiment the plan was to apply both manure and fertilizers in the fall. Since 1919 spring application of fertilizers has been the rule. Fall application of manure has been the rule since 1914. During all years except 1932 fertilizers were broadcast. In 1932 they were applied in the row.

Since each of the crops in the rotation appears every year, there are four series of plats in the experiment. Each series consists of nine plats, corresponding with the treatments outlined above. All treatments except one appear in duplicate. The combination manure plus phosphate, plus limestone, plus potassium appears on only one plat.

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[4] The number of replicates was the same on the other three series, but the serial arrangement was different. Since the question of the serial arrangement of the plats in each series does not enter into the present discussion, all subsequent references to the several series of plats used in these trials treats them as though each was arranged as in series I. The corn crops of 1924, 1928, and 1932 were on series I, the crops of 1925 and 1929 on series VI, and the crop of 1927 on series X. The roman series numbers refer to the permanent field designations used at the North Dakota Agricultural Experiment Station.

Only one of the four series, namely, the one on which corn was planted, received fertilizer at the beginning of the experiment. Therefore, the total amount of fertilizer applied to date differs for the different series depending upon the number of rotation cycles that have been completed in each case. Furthermore, owing to an error during one of the earlier years an overdose of the commercial fertilizer was applied to one of the series. The error consisted of applying the fertilizer in the spring after having already applied it in the fall. Moreover, twice the standard amount of phosphate was used by mistake in the spring application.

Table 2 shows the amounts of P_2O_5 in the phosphate fertilizers applied to each of the corn crops involved in the present study.

TABLE 2.—*Amount of P_2O_5 in phosphates used on phosphated plats, pounds per acre.*

Crop year	P_2O_5 applied to current crop	Average application per corn crop since beginning of soil treatment	Total P_2O_5 applied since beginning of soil treatment
1924.......	66.0	102.3†	409.4†
1925.......	66.0	65.0	260.0
1926.......	66.0	65.0	260.0
1927.......	66.0	65.5	262.0
1928.......	64.6	94.8	474.0
1929.......	66.0	65.2	326.0
1930.......	66.0	65.2	326.0
1932.......	75.9*	91.6	549.8

*Overdose applied due to faulty operation of fertilizer attachment.

†Through an error, an application was made in the spring of 1912 as well as in the fall of 1911.

Table 3 shows the amount of manure applied to the corn crop. The headings are self explanatory.

TABLE 3.—*Application of manure on manured plats, tons per acre.*

Crop year	Amount applied per plat to current crop	Average application per corn crop since beginning of soil treatment	Total amount applied per plat since beginning of soil treatment
1924.......	9.5	11.7	47.0
1925.......	10.0	10.1	40.7
1926.......	9.5	9.5	38 0
1927.......	8.5	10.6	42.5
1928.......	10.9	11.6	57.9
1929.......	10.4	10.2	51.1
1930.......	6.7	8.9	44.7
1932.......	7.2	10.9	65.2

The variety of corn grown was Minnesota No. 13, of the Thorpe strain, except during the first year when Mercer flint was used. The former, in the environment of this experiment, occupies the average season fully. The latter is a little later in maturity.

The comparative advancement of the crop under the various treatments has been determined at harvest time in most cases. The procedure was to divide the crop from each plat into a mature and immature lot and determine the percentage of each. During 3 of the 8 years the date of silking was taken as the criterion. The proportion of the crop silked was determined on given dates. The data are presented in Table 4.

TABLE 4.—*Percentage of fully matured corn and of plants silked on plats receiving various fertilizer treatments.*

Treatment	1924	1925	1926	1927	1928*	1929*	1930*	1932
None	29	50	25	41	47	29	32	38
Manure	34	54	24	36	67	41	39	39
Manure+P	38	69	31	38	77	52	56	46
Manure+P+L	34	64	36	43	84	60	45	43
None	26	69	26	36	41	46	40	35
Manure	23	62	27	35	55	44	51	38
Manure+P	30	67	37	43	73	60	58	55
Manure+P+L	29	70	38	47	71	60	40	40
Manure+P+L+K	27	77	23	44	66	68	42	52

*Percentage of plants silked.

EFFECT OF PHOSPHORUS

The data for each of the duplicated plats rather than the averages are presented for the purpose of emphasizing the consistency of the superiority of the phosphorus plats over those receiving no phosphorus. The effect of phosphorus may be noted on comparing the members of the two pairs, *viz.*, 2 and 3 and 6 and 7. This affords a total of 16 separate comparisons and in every case the difference is in favor of the phosphorus plat. There can be little doubt as to the statistical significance of these differences in view of their consistency. As a matter of fact, when tested by "Student's" method as applied to paired comparisons, the odds are found to be better than 9999 : 1.

The degree of difference is shown by the figures given below (Table 5) which represent the average for each of the treatments covering the 5 years during which the maturity of the crop was determined at harvest time.

TABLE 5.—*Percentage of corn matured under various fertilizer treatments, 5-year average.*

Treatment	Percentage of crop matured
None	35.7
Manure	35.8
Manure+P	43.6
Manure+P+L	42.7
Manure+P+L+K	40.0

The difference in days was determined for the years 1928, 1929, and 1930. For this purpose the date was noted on which 50% of the plants in each plat were in silk. The data are presented in Table 6.

TABLE 6.—*Date of silking of corn under various fertilizer treatments.*

Treatment	Date 50% silked		
	1928	1929	1930
None	Aug. 5	Aug. 1	Aug. 8
Manure	Aug. 3	July 30	Aug. 3
Manure+P	Aug. 1	July 28	Aug. 1
Manure+P+L	Aug. 1	July 27	Aug. 1
None	Aug. 5	July 30	Aug. 5
Manure	Aug. 4	July 30	Aug. 4
Manure+P	Aug. 2	July 28	Aug. 3
Manure+P+L	Aug. 2	July 28	Aug. 5
Manure+P+L+K	Aug. 3	July 26	Aug. 2

In each of the 3 years phosphorus advanced the crop about 2 days up to a stage which is about midway of its normal growth period. In the average growing season, which extends from about May 15 to September 20, upwards of 50% of the plants of the variety used in this experiment will have completed their growth and reached full maturity at the time of the first killing frost. Of the remaining 50%, one-half or more normally are sufficiently mature to produce good merchantable corn.

The combination manure and phosphorus appears to have hastened development by about 3 days as an average of the two pairs of plats 1 and 3 and 5 and 7. The extremes of difference are 2 to 6 days, the first pair of plats consistently showing a greater difference than the second.

EFFECT OF OTHER FERTILIZERS

There is no evidence that any other single ingredient of the fertilizers applied has had any consistent effect either in advancing or suppressing the development of the crop. Reference to Table 7, which presents the averages of the duplicated plats, shows that there is no constant relation between items 3 and 4, which would show the effect of lime, or between items 4 and 5 which would show the effect of potassium.

TABLE 7.—*Percentage of fully matured corn and of plants silked on plats receiving various fertilizer treatments, average of duplicate plats.*

Item No.	Treatment	1924	1925	1926	1927	1928	1929	1930	1932
1	None	27.5	58.5	25.5	38.5	44.0	37.5	36.0	26.5
2	Manure	28.5	58.0	25.5	35.5	61.0	42.5	45.0	38.5
3	Manure+P	34.0	64.0	34.0	41.0	75.0	56.0	57.0	50.5
4	Manure+P+L	31.5	67.0	37.0	45.0	77.5	60.0	42.5	41.5
5*	Manure+P+L+K	27.0	77.0	23.0	44.0	66.0	68.0	42.0	52.0

*Single plat.

EFFECT OF MANURE

Manure has had some effect in advancing maturity, but this effect has been markedly influenced by seasonal conditions. This fact is well shown in Table 4, and is supported by data from another series of plats. These data are presented in Table 8. They represent a maturity determination on a series of rotation experiments. In the case of each of the rotations indicated in the left-hand column of the table, half of the set of plats receives manure and the other does not. In all other respects the two halves are identical. The figures in the body of the table represent the difference in percentage of mature corn between the manured and unmanured plats. The great preponderance of positive differences indicates that manure has had an effect upon maturity, but it is equally apparent from the low order of difference in many cases, coupled with the smattering of minus signs, that such effect is of doubtful significance.

TABLE 8.—*Effect of manure on maturity of corn.*

Rotation*	Excess of proportion of mature corn on manured over that on unmanured plats								
	1924	1925	1926	1927	1928†	1929†	1930†	1932	Odds
C, B, Sw. Cl., W...	0	21	1	6	32	14	2	7	48.0 to 1
C, B, G, M, W.....	—8	9	17	—9	8	8	6	—9	2.8 to 1
C, B, P, W........	—1	7	—2	—7	4	37	—29	10	1.8 to 1
C, R, W, Sw. Cl....	0	0	5	1	23	7	13	15	59.0 to 1
C, B, W, Sw. Cl....	8	3	7	1	33	25	16	8	184.0 to 1
C, W, B, G, M, Fl, W		19	10	—4	29	—13	—10	8	9.4 to 1
Continuous corn...		9	11	6	29	23	13	4	587.0 to 1

*Abbreviations: C = corn; B = barley; Sw. Cl. = sweet clover; W = hard red spring wheat; P = field peas; R = winter rye; G.M. = German millet; Fl = flax

†Percentage of plants silked.

RELATION OF MATURITY TO YIELD

Is advanced maturity achieved simply in proportion to the growth stimulus afforded by the application of something in which the soil is deficient? Salter (10) obtained the greatest advance of silking date on those corn plats which returned the highest yields. Such plats received complete fertilizer. Schuster (11) reported in the case of soybeans that, in general, those applications which produced the highest yields also produced the highest percentage of maturity. Hepler and Kraybill (4), on the other hand, emphasized the lack of relation between maturity and yield. They pointed out that the marked advance in maturity in tomatoes resulting from the application of superphosphate was not simply another manifestation of phosphate deficiency as measured by increased yield.

In Table 9 the rank of each plat as to maturity is set side by side with its rank as to yield. The two treatments, manure plus P and manure plus P plus L, stand out as occupying the higher ranks as to both maturity and yield. No treatment, on the other hand, consistently occupies the lower ranks as to both maturity and yield. Although the situation under these three treatments suggests a relationship, on the whole there is no evidence of high correlation. This is more clearly brought out in the scatter diagram, Fig. 1. This diagram is based upon the ranks of the individual plats rather than upon the averages of the duplicated plats. The correlation coefficient calculated from the 63 items making up the scatter diagram is 0.194 ± .068.

TABLE 9.—*Relation of maturity to yield of corn.*

Treatment	1924		1925		1926		1927		1928		1929		1930		1932	
	M*	Y†	M	Y	M	Y	M	Y	M	Y	M	Y	M	Y	M	Y
None........	4	5	4	5	3	4	4	5	5	5	5	4	5	5	5	1
Manure......	3	3	5	3	4	2	5	4	4	4	4	3	2	4	4	2
Manure+P...	1	2	2	2	2	3	3	2	2	1	3	1	1	2	2	5
Manure+P+ L..........	2	1	3	1	1	1	1	3	1	3	2	2	3	1	3	3
Manure+P+ L+K......	5	4	1	4	5	–	2	1	3	2	1	5	4	3	1	4

*Maturity rank. 1 = highest maturity; 5 = lowest maturity.
†Yield rank.

	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5
1.5	1	1			1			4
2.5	1		2	1	2			
3.5	2	2	1	1				3
4.5		1		2	3			
5.5		1	1	1	1	2	1	1
6.5	3		2			2		
7.5		1	1			1	2	2
8.5	1			2		2	4	4

r = 0.194 ± .068

FIG. 1.—Scattergram showing correlation of maturity and yield.

HAS PHOSPHORUS APPLICATION BEEN PROFITABLE?

It has been established that phosphorus has definitely advanced the maturity of the corn-crop. The degree to which it has been advanced is small, however, and would, by itself, hardly represent a sufficient advantage to justify the expense of phosphorus application under the conditions of this experiment. If, on the other hand, this advantage has been gained in addition to a profitable increase in yield, it assumes practical significance.

Since the 150 pounds of phosphate constituting the unit of application have been applied only once during a 4-year rotation period, it is necessary to add up the average yields of each of the four crops, namely, oats, wheat, corn, and clover, in order to give proper credit to phosphorus. In Table 10, the yields are given for the grain crops named. Clover yields are not included because they are available for only 3 out of the 8 years in the period, due to winterkilling of the clover.

TABLE 10.—*Effect of phosphorus on yield of corn, oats, and wheat, average annual yields during an 8-year period, 1924–31.*

Crop	Manure	Manure + phosphorus	Difference in favor of phosphorus	Odds*
Corn	30.5	32.8	2.3	14:1
Oats	71.8	75.8	4.0	45:1
Wheat	33.9	36.3	2.4	103:1

*"Student's" method for paired comparisons.

The odds suggest some doubt as to the significance of the increase in the case of corn. Taken at their face value, the combined increases are sufficient to cover the cost of the phosphorus. The cost of the fertilizer has ranged from about $2.75 to $4.00 per acre. It would seem, therefore, that the enhanced maturity of the crop essentially represents the margin of profit from phosphorus under the conditions of this experiment.

In this connection it is important to call attention to the striking results obtained during the past decade by a number of investigators, among them Truog (14) and Salter (10), which demonstrate much greater effects from fertilizers applied in the hill than from those applied broadcast. Their results strongly suggest that even more marked effects upon both maturity and yield might have been obtained if the 150 pounds of treble superphosphate used in the present experiment had been applied in the hill rather than broadcast.

SUMMARY

The comparative maturity of corn was studied during an 8-year period on plats receiving various soil treatments.

Phosphorus advanced maturity significantly. During 3 of the 8 years when the date on which plants silked in the various plats was determined, it was found that phosphorus had advanced silking about 2 days. The combination of manure and phosphorus advanced the silking date about 3 days during this period.

Lime or potassium did not influence maturity consistently. Manure advanced maturity somewhat. During 3 consecutive years that date of silking was noted, the crop was definitely advanced on the manured plats. The differences during the other years were of a low order in the majority of cases.

The correlation between yield rank and maturity rank was low.

The increased maturity of the crop was not sufficient in degree to warrant, by itself, the application of phosphorus. However, the increased yield of corn, wheat, and oats, all of which was a credit to phosphorus since the application was made only once during a rotation period including these crops, was apparently sufficient to cover the cost of application. The enhanced maturity, therefore, essentially represented the margin of profit from the soil treatment.

LITERATURE CITED

1. BRAND, CHAS. J. Introductory statement (in) The influence of fertilizers on Crop Quality. Proc. 8th Ann. Conv. Nat. Fert. Assoc., Sec. 2: 2–3. 1932.

2. BLACKWELL, C. P., and BUIE, F. S. Fertilizer experiments. S. Car. Agr. Exp. Sta. Bul. 209. 1921.
3. HARTWELL, BURT L. The Influence of Fertilizers on Crop Quality. Proc. 8th Ann. Conv. Nat. Fert. Assoc., Sec. 2: 5–56. 1932.
4. HEPLER, J. R., and KRAYBILL, H. R. Effect of phosphorus upon the yield and time of maturity of the tomato. N. H. Agr. Exp. Sta. Tech. Bul. 28. 1925.
5. HOPPER, T. H., and WALSTER, H. L. Soil survey of Cass County, North Dakota; II. The chemical composition of the soils of Cass County. Ser. 1924, No. 29: 53–80. 1924.
6. KNOBEL, E. W., PEIGHTAL, M. F., and CHAPMAN, J. E. Soil survey of Cass County, North Dakota. Ser. 1924, No. 29: 24–27; 63. 1924.
7. MUSGROVE, G. W., and COE, D. G. Influence of fertilizer treatment on maturity and yield of cotton. Jour. Amer. Soc. Agron., 19: 910–923. 1927.
8. NOLL C. F. Effect of phosphate on early growth and maturity. Jour. Amer. Soc. Agron., 15: 87–99. 1923.
9. OLSON, P. J. Tasseling and silking as criteria of earliness in corn. Jour. Amer. Soc. Agron., 19: 454–460. 1927.
10. SALTER, Robert M. Fertilizing for higher quality. Phosphorus Digest, March, 1931: 2–6. 1931.
11. SCHUSTER, GEO. L. Influence of fertilizers on yield and maturity of soybeans. Jour. Amer. Soc. Agron., 14: 193–197. 1922.
12. ————. Fifteen years of experiments with manure, fertilizers, and lime. Del. Agr. Exp. Sta. Bul. 137. 1924.
13. SKINNER, J. J., and PATE, W. F. The influence of potassium on cotton bolls and foliage on a potassium deficient soil. Jour. Amer. Soc. Agron., 17: 550–556. 1925.
14. TRUOG, EMIL, *et al.* Fertilizer experiments. Wis. Agr. Exp. Sta. Res. Bul. 65. 1925.
15. WILLIAMS, C. B. Wise use of fertilizers on cotton; their effect upon yield and maturity for different soils in North Carolina. Jour. Amer. Soc. Agron., 18: 1036–1044. 1926.

TURKESTAN ALFALFA AS COMPARED WITH GRIMM FOR WILT-INFECTED SOILS IN IOWA[1]

F. S. WILKINS AND H. L. WESTOVER[2]

Turkestan alfalfa was first introduced into the United States through the efforts of the U. S. Dept. of Agriculture in 1898. The early importations appeared so promising in the cold, dry regions that a considerable demand was created for seed from that source and at times the importations have amounted to several million pounds annually. Since 1920, however, importations have been rather limited and no Turkestan seed reached the United States through commercial channels during 1930, 1931, and 1932. As was to be expected, much of the Turkestan seed was marketed in the eastern states where climatic conditions do not favor seed production and as a result of which growers depend upon purchasing seed from outside sources. This alfalfa gave unsatisfactory results in the East owing to its low productivity and short survival, both of which may be attributed mainly to the susceptibility of Turkestan alfalfa to certain leaf diseases and to its tendency to early fall dormancy.

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[1] Joint contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. (Project No. 3901). Journal paper No. B 109 of the Iowa Agricultural Experiment Station. Project No. 170. Received for publication April 10, 1933.

[2] Research Assistant Professor in Farm Crops, Iowa Agricultural Experiment Station, and Senior Agronomist, U. S. Dept. of Agriculture, respectively. The writers gratefully acknowledge the assistance of Professor George W. Snedecor, Statistician of the Iowa Agricultural Experiment Station, for advice in making the statistical interpretations, and of L. D. Eagles, Assistant in Forage Crop Investigations of the Iowa Agricultural Experiment Station for calculating the data.

In numerous tests conducted in the East and South, the average annual yields of Turkestan alfalfa usually have been a ton or more per acre less than was obtained from some of the domestic alfalfas and stands are frequently seriously depleted in one or two years. Even in the northern Great Plains where Turkestan alfalfa has shown up to best advantage, it has seldom exceeded Grimm alfalfa in yield. Since numerous tests had shown that Turkestan alfalfa was not adapted for general agricultural use in the United States, the Secretary of Agriculture issued a notice in June 1926 requiring that Turkestan seed be stained 10% red before being permitted entry. Not long thereafter bacterial wilt (*Phytomonas insidiosa* Mc C.) began to assume serious proportions in some of the best alfalfa-growing districts; and since Turkestan alfalfa had been found to possess considerable wilt resistance, the interest in seed from that source was renewed. As a result numerous samples of seed from all parts of Turkestan have been tested to determine their productivity as compared with domestic alfalfas as well as their reaction to wilt and cold. While more or less variation has been found in the different lots of seed, that obtained from the important seed-producing districts has proved quite wilt and cold resistant. All lots so far tested are quite susceptible to certain leaf diseases. Plat tests conducted in various parts of the United States have shown that in the west central part of the Mississippi Valley and in the intermountain region where wilt is prevalent, domestic alfalfas are generally more productive than Turkestan for two or three years, but where the fields are retained for longer periods Turkestan alfalfa is likely to give higher average yields owing to the thinning out by the disease of the alfalfas generally grown. Since Turkestan alfalfa is of advantage in restricted areas, the Secretary of Agriculture issued a notice in 1933 changing the stain requirement of imported seed from 10% red to 10% purple-red.

Turkestan alfalfa has been grown by an occasional Iowa farmer for many years but apparently the acreage remains limited. The resistance of Turkestan alfalfa to bacterial wilt and cold under Iowa conditions is clearly demonstrated in the experiments that have been conducted at Ames, but yields have been somewhat less than for the kinds more generally grown. As has been frequently observed elsewhere, Turkestan alfalfas have proved particularly susceptible to leaf diseases. Since wilt is responsible for shortening the survival of alfalfa in parts of Iowa, the results of tests comparing Turkestan alfalfa with Grimm, one of the standard varieties in this state, should be of considerable interest.

PRELIMINARY TEST, 1926–1930

In 1926, 76 lots[3] of alfalfa, representing all the named variegated alfalfas of which seed was commercially available and most northern strains of common, were sown in 1/160 acre plats in wilt-infected soil. Unfortunately, Turkestan, which was the only kind that demonstrated definite resistance to bacterial wilt, was represented by only one lot of seed obtained from a 15-year-old field in South Dakota. Grimm was well represented with nine lots and the Turkestan alfalfa is compared with the average of the nine. At the conclusion of the test in 1930 the stand of Turkestan alfalfa was far superior to that of any of the other lots tested.

The average acre yields for the three crop years, 1927–29, inclusive, were Turkestan 3.45 tons and Grimm 3.69, a difference of 0.39 ton being required for significance.[4] Grimm was superior in yield the first 2 years and Turkestan the last year. In percentage of Grimm, the yields of Turkestan for the 3 years in order were 80, 96, and 106.

MAJOR TESTS 1928 to 1932

EXPERIMENTAL PROCEDURE

These tests were located on two distinct soil types, three fields being on Carrington loam and three on O'Neill sandy loam. Seedings made in 1928 or later included 27 lots of Turkestan alfalfa sown in 65 plats in six fields as follows: Field A, two lots in triplicate in 1928; Field B, four lots in triplicate in 1929; Field C, four lots in quadruplicate in 1929; Field D, five lots singly in 1929; Field E, five lots singly in 1929; and Field F, seven lots in triplicate in 1931. The plats varied in size from 1/160 to 1/75 acre, the larger size predominating. Yields are based on the weight of forage from the middle 4 feet of each plat, 16 inches on each side being discarded to eliminate the border effect. Each test included numerous lots of imported and domestic alfalfas, but in this paper comparison is limited mainly to Turkestan and Grimm. In three of the fields Grimm was used every third or fifth plat as check, and in three other fields several different lots of Grimm in random distribution were used. When data were calculated, each yield of Turkestan was paired with the yield of the nearest Grimm plat. Although initial stands of Grimm were slightly better than of Turkestan, it is felt that stands of both were good enough to give maximum yields.

Bacterial wilt caused marked decreases in yield only in Field A, planted in 1928. These decreases did not occur until the fourth year. In Field B crops have been harvested three seasons, 1930 to 1932. In both fields wilt was 1 year later in developing than would have been the case had the organism been present in the soil when seedings were made. The soil in fields C, D, and E was already infected with the wilt organism at the time of seeding and yields were obtained only two seasons because of excessive weediness in the third year. Field F is new, the first crops having been harvested in 1932.

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[3] In this paper lot is used to designate the plants grown from a particular sample of alfalfa seed or a field from which a seed sample was obtained.

[4] FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1932. This work was followed throughout for statistical interpretations.

During the two normal seasons 1929 and 1932, three cuttings were obtained but in the critically dry seasons of 1930 and 1931 the alfalfa was harvested only twice. Yields obtained represent green, weed-free alfalfa weighed within 3 minutes after cutting and are reported on a uniform air-dry basis. The data are based on a total of 34 crops for which there were 343 determinations each of Turkestan and Grimm alfalfa. In order to economize in space and at the same time permit summarized presentation, these data have been combined and weighted averages are given in Tables 1, 2, 3, and 4.

YIELD COMPARISONS

The probability is statistically high that as a total for 1 or more years Grimm will outyield Turkestan alfalfa. Average yields of Turkestan are lower than those of Grimm for every crop in each of the six fields except for Field C in 1931 and Field A in 1932 in both of which the stands of Grimm alfalfa had been thinned by the bacterial wilt.

The data indicate that the greatest sacrifice in yield from the use of Turkestan may be expected in the first year. Such data are available from six fields and the average total yield for three cuttings was 4.04 tons per acre for Grimm and 76% as much, or 3.06 tons, for Turkestan (Table 1). As 64 pairs of plats were used in this summary, the data should be dependable.

TABLE 1.—*Average yields of Turkestan and Grimm alfalfa for fields A, B, C, D, E, and F for the first crop year, data for 64 pairs of plats.*

Crop	Yields, tons per acre		Turkestan in % of Grimm
	Turkestan	Grimm	
First	1.83	2.24	82
Second	0.75	1.01	74
Third	0.48	0.79	61
Total	3.06	4.04	76

First and second year data are available from a total of 44 pairs of plats from five fields, average yields being given in Table 2. The first year Grimm yielded an average total for three cuttings of 3.76 tons per acre and Turkestan 80% as much, or 3.02 tons. The second year the average total yield of Turkestan was 2.23 tons per acre for two cuttings, being 95% as much as Grimm which yielded 2.35 tons. This difference of 5% in favor of Grimm for the second year is not significant, but the difference in the total yield for 2 years with 6.11 tons per acre for Grimm and 5.25 tons or 86% as much for Turkestan is significant.

Apparently about the same differences may be expected in the third as in the second year. Three years' data from 18 pairs of plats from two fields are given in Table 3. In these fields Turkestan yielded 66% as much as Grimm the first year, 93% as much the

TABLE 2.—*Average yield of Turkestan and Grimm alfalfa for fields A, B, C, D, and E for the first and second crop years, data for 44 pairs of plats.*

Crop	Yields, tons per acre		Turkestan in % of Grimm
	Turkestan	Grimm	
	First Year		
First	1.80	2.03	89
Second	0.78	1.04	75
Third	0.44	0.69	64
Total	3.02	3.76	80
	Second Year		
First	1.60	1.68	95
Second	0.63	0.67	94
Total	2.23	2.35	95
Total, 2 years	5.25	6.11	86

second year, and 89% as much the third year. The total yield for Grimm alfalfa for the 3 years was 8.23 tons per acre and of Turkestan 6.66 tons, or 81% of Grimm.

In the fourth year, shortly before the first crop of field A was removed, Grimm plants began dying generally from bacterial wilt. The stand of Turkestan was not noticeably reduced throughout the season. For the first crop there was a difference of 5% in yield in favor of the Grimm which was practically the same as the difference of the previous year (Table 4). By the time the second crop was re-

TABLE 3.—*Average yields of Turkestan and Grimm alfalfa for fields A and B for the first, second, and third crop years, data for 18 pairs of plats.*

Crop	Yields, tons per acre		Turkestan in % of Grimm
	Turkestan	Grimm	
	First Year		
First	1.21	1.71	71
Second	0.48	0.82	59
Third	0.48	0.76	63
Total	2.17	3.29	66
	Second Year		
First	1.62	1.69	96
Second	0.48	0.57	84
Total	2.10	2.26	93
	Third Year		
First	1.36	1.48	92
Second	1.03	1.20	86
Total	2.39	2.68	89
Total, 3 years	6.66	8.23	81

TABLE 4.—*Average yields of Turkestan and Grimm alfalfa for field A for the first, second, third, and fourth crop years, data for six pairs of plats.*

Crop	Yields, tons per acre		Turkestan in % of Grimm
	Turkestan	Grimm	
	First Year		
First	1.36	1.68	81
Second	1.09	1.58	69
Third	0.48	0.76	63
Total	2.93	4.02	73
	Second Year		
First	1.81	1.86	97
Second	0.59	0.73	81
Total	2.40	2.59	93
	Third Year		
First	1.34	1.41	95
Second	0.37	0.41	90
Total	1.71	1.82	94
	Fourth Year		
First	1.88	1.98	95
Second	1.45	0.90	161
Third	0.75	0.55	136
Total	4.08	3.43	119
Total, 4 years	11.12	11.86	94

moved so many of the Grimm plants had died that the percentage yield of Turkestan was 161 with Grimm as 100. For the third crop the percentage yield of Turkestan was 136. The total percentage yield from the fourth season of Turkestan alfalfa was 119 with an average yield from six pairs of plats of 4.08 tons per acre as compared with 3.43 tons for Grimm.

Most of these data were obtained in the critically dry seasons of 1930 and 1931. Rainfall was so limited during the growing seasons that in parts of all fields the third crop failed to develop. It is believed that Turkestan was favored by these conditions. Data for 12 pairs of plats in field B are available for the critically dry year of 1931 and the normal year of 1932. With satisfactory stands of both kinds of alfalfa, Turkestan yielded 93% as much as Grimm in 1931 and 87% as much in 1932, as a total for first and second crops. While the difference is in favor of Grimm in the normal season, it is not statistically significant. Further tests are needed to determine whether Grimm has a greater advantage over the Turkestan in normal than in dry seasons.

The data indicate that unless stands of Grimm are depleted by wilt, Turkestan may be expected to yield less in proportion to Grimm as the growing season progresses. With two exceptions caused by wilt the yield of Turkestan in percentage of Grimm is less for the second crop than for the first and less for the third crop than for the second in each of the four series of averages given in Tables 1, 2, 3, and 4. In field A wilt had seriously depleted the stands of Grimm by the time second and third crops were removed in the fourth year (Table 4).

The most reliable data showing the progressively lower yields of Turkestan are contained in Table 1 where average yields for the first year from all of the 64 pairs of plats in six fields are given. The yields of Turkestan in percentage of Grimm were 82 for the first crop, 74 for the second, and 61 for the third.

COMPARISON OF TURKESTAN AND HARDISTAN ALFALFAS

Hardistan alfalfa was so named by Kiesselbach and associates[5] of the Nebraska Agricultural Experiment Station, seed having been obtained from an old Nebraska field of alfalfa for which Turkestan origin was quite definitely established. As regards resistance to cold and wilt and susceptibility to leaf diseases, Hardistan alfalfa is very similar to the better strains from Turkestan. It was included in the test sown in field C and in yield performed similarly to the average of four Turkestan lots in this experiment.

The average yield of Turkestan alfalfa from quadruplicate seedings exceeded that obtained from Hardistan in 1930, but in 1931 the reverse was true. In 1930 Turkestan yielded 3.89 tons per acre, Hardistan 3.02, and Grimm 4.30. The poorer showing made by Hardistan the first crop year may have been due to the heavy mixture of foxtail in the alfalfa seed. Total yields for three crops in 1931 were 3.18 tons per acre for Turkestan, 3.57 for Hardistan, and 3.14 for Grimm. Grimm was injured during the preceding winter in a poorly drained area of the field and the stand began to become thinned by wilt in midsummer of 1931.

In the spring of 1932, at the conclusion of the test including 16 representative varieties or sources of seed, the estimated stands of the three best were Turkestan 76%, Hardistan 68%, and Ladak 60%, as compared with 40% for Grimm. The total yields of the six crops harvested in 1930–31 were Ladak 7.61 tons per acre, Grimm 7.44 tons, Turkestan 7.07 tons, and Hardistan 6.59 tons. Initial stands for all plats of domestic and Turkestan alfalfas in the test were excellent both in the fall of the seeding year, 1929, and a year later. Ladak, Turkestan, and Hardistan suffered practically no winterkilling or other apparent injury in 1930–31, while the winterkilling in all of the other domestic alfalfas was estimated at 8 to 29%. There was evidence also of injury to the remaining plants. Ordinarily variegated alfalfas do not winterkill at the Iowa Experiment Station, but the conditions in this field were particularly severe. In 1931–32 the winterkilling in Ladak alfalfa was estimated at 31%, Turkestan 21%, and Hardistan 23%, with the other kinds ranging from 41 to 63%. Further tests are needed to determine the productivity of Hardistan alfalfa under Iowa conditions.

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[5] KIESSELBACH, T. A., ANDERSON, ARTHUR, and PELTIER, G. L. A new variety of alfalfa. Jour. Amer. Soc. Agron., 22: 189–190. 1930.

VARIETAL RECOMMENDATIONS FOR IOWA

Previous to about 1925 the variegated varieties of alfalfa were recommended in all parts of Iowa. Bacterial wilt infestation has since become general in the older and larger producing sections, necessitating qualification of recommendations. Since the disease was first observed at the Iowa Agricultural Experiment Station in 1921, yields have been obtained from about 500 lots of alfalfa sown in triplicate plats 1/160 acre or larger in size. All named varieties, and in general all of the domestic and world sources of variegated and common alfalfa seed, have been represented in these tests. In most cases, tests have been conducted on soils that were known to be infected with the wilt organism, and under such conditions susceptible alfalfas have usually produced profitable crops for three seasons. The depletion of stands by bacterial wilt and winter injury usually have been responsible for the termination of the tests at the end of the third crop season. In one of the fields, where drainage was inadequate, the test was terminated at the end of the second crop season because of stand depletion.

In general the variegated sorts have been more resistant to winter injury, while most common alfalfas have appeared to be somewhat more resistant to bacterial wilt. These results confirm the tests of others. Bacterial wilt and winter injury together have depleted stands of variegated and the more hardy common alfalfas in about the same ratio by the end of the third crop year.

In the presence of wilt, yields of Grimm, Baltic, Hardigan, Ontario Variegated, Cossack, and Dakota and Montana common alfalfas have been about equal as indicated by statistical analysis of the data. Montana and Dakota common have been superior in yield to common alfalfa from other sources, and where the soil is so infected with wilt that susceptible alfalfas survive only 2 or 3 years these sorts are preferable to any of the variegated sorts except Ladak because of difference in cost of seed. Ladak has yielded well in the fields in which it has been included and has shown considerable resistance to bacterial wilt and heaving. It also has proved somewhat superior to Grimm in cold resistance.

While Turkestan alfalfa survives longer than other alfalfas in the presence of wilt, it is not recommended in short rotations. The yield obtained from it is usually a ton or more less per acre than would be obtained from Grimm as a total for two or three crop seasons and this difference is more than enough to pay the cost of seeding a new field when the greater value of the alfalfa residue in the short rotation is considered. On the other hand, while the Iowa tests are inadequate, it is probable that Turkestan will maintain a satisfactory stand 4, 5, or 6 years even when the wilt organism is present. Apparently, Turkestan has a place in Iowa for those growers who are willing to sacrifice yield to gain longevity.

Bacterial wilt is seldom reported in sections of Iowa where the acreage is limited or where alfalfa is a comparatively new crop, and in the absence of the disease Turkestan alfalfa does not have a place in Iowa. Under such conditions farmers may well continue to sow variegated alfalfas or, if necessary to economize in cost of seed, Montana or Dakota common may be used to advantage.

WATER CONTENT OF TURKESTAN AND GRIMM ALFALFA

As previously indicated, Turkestan alfalfa is more susceptible than Grimm to leaf diseases which frequently cause drying and shedding of a considerable proportion of the leaves before harvesting. This condition is more likely to develop on the second or third crops and when prevalent the plants appear much less succulent than those not so affected. To obtain definite information on the moisture content of Turkestan alfalfa attacked by leaf diseases and of Grimm in normal condition, 150 shrinkage determinations were made. Samples were obtained from three fields representing first, second, and third cuttings for 3 years and involving seven lots of Turkestan alfalfa. Comparisons were made with samples from adjoining plats of Grimm. From four to nine samples weighing 3 to 5 pounds were taken for each lot at each cutting. The samples were first dried to about 2% moisture at approximately 80° C then chopped, after which 1-pound samples were reduced to a water-free basis at a temperature of 100° C.

In 19 direct comparisons made at different times or in different fields, Turkestan averaged 72.2% and Grimm 72.1% water at the time of cutting. Water content of both alfalfas varied between 66% and 76%, depending largely upon the stage of development when cuttings were made. In 7 of the 19 comparisons Turkestan contained slightly more water than Grimm, while in 7 others the reverse was true. In two of the comparisons the mean water content of Turkestan was significantly higher than that of Grimm and in three others the reverse was true. Since there were significant differences in only 5 out of 19 comparisons, and since the results in these cases were contradictory, it would appear that the water content of Turkestan and Grimm alfalfas is very similar when they are grown under comparable conditions. The only significant differences occurred in 1932 with plentiful soil moisture. Both lots of Turkestan alfalfa in the second crop of field A were significantly lower in water content than Grimm. Grimm averaged 74.0% with one Turkestan 71.9% and the other 71.0%. In field B the moisture content in one lot of Turkestan exceeded Grimm 3.0% and 2.5%, respectively, for second and third crops, and another lot contained 2.2% less moisture than Grimm in the second crop. These data indicate that the difference in moisture content of Grimm and Turkestan alfalfa is so slight that yield data may be based on green weights as has been done in the preceding part of this paper.

SUMMARY AND CONCLUSIONS

Tests with Turkestan alfalfa have been in progress at the Iowa Agricultural Experiment Station since 1926 and have included 27 lots of imported seed and 2 domestic lots of Turkestan origin.

Of about 500 lots of alfalfa included in yield trials at the Iowa Experiment Station, Turkestan, Hardistan, and Ladak are the only kinds that have demonstrated marked resistance to bacterial wilt, *Phytomonas insidiosa* McC. Under conditions of relatively poor drainage these alfalfas have also demonstrated their superiority in cold resistance to the variegated alfalfas generally grown. Turkestan, however, is particularly susceptible to leaf diseases. Hardistan is also susceptible but apparently to a lesser degree.

Statistically, the probability is high that as long as stands of Grimm are maintained it will yield more than Turkestan. Apparently, it is necessary for the grower of Turkestan alfalfa to sacrifice a ton or more of hay per acre as a total for two or three crop years.

With varieties susceptible to bacterial wilt profitable crops usually have been harvested for three crop years on wilt-infected soils at the Iowa Agricultural Experiment Station.

Apparently the loss in yield from growing Turkestan is more than enough to pay the cost of reseeding when the greater value of the residue in the short rotation is considered. It would seem, however, that Turkestan has a place on wilt-infected soils of Iowa for those growers who desire to sacrifice yield to gain longevity. Turkestan does not have a place in Iowa where bacterial wilt has not yet made its appearance. In a 2-year test Hardistan and Turkestan gave similar results.

The choice of varieties for wilt-infected soils in Iowa appears to lie between Cossack, Grimm, Dakota, or Montana common for short rotations and Turkestan, Hardistan, and Ladak for long rotations. For soils not infected with bacterial wilt farmers may well continue to choose the variegated alfalfas.

STUDIES OF IRRIGATION METHODS FOR SUGAR BEETS IN NORTHERN COLORADO[1]

H. E. BREWBAKER[2]

The problem of efficient application of irrigation water is one of paramount importance to the irrigation farmer. With a shortage in reservoir supply, such as occurred in 1931 and 1932 in northern Colorado, and with a limited direct-flow water right, it is necessary for the irrigation farmer to choose carefully the best method of applying the water at his disposal.

It is a natural tendency in an area characterized by fairly adequate spring rainfall to delay the first application of water as long as possible. This is especially true of the farmer who depends in part or entirely on water stored in a reservoir, and who through deferring the early irrigation until a later date, can provide for later irrigation of crops. Further, many irrigation farmers believe that early irrigation produces short roots, whereas a delay in first irrigation forces the beet plant to root more deeply and to develop longer and better-shaped beets.

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[1] Contribution from the Division of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Colorado Agricultural Experiment Station, Fort Collins, Colo. Received for publication April 13, 1933.

[2] Associate Agronomist. Grateful acknowledgment is made to A. W. Skuderna and G. H. Coons, Principal Agronomist and Principal Pathologist, respectively, Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, for helpful suggestions and criticisms in connection with the conduct of the study and preparation of this manuscript, and to R. L. Parshall, Senior Irrigation Engineer, Bureau of Agricultural Engineering, U. S. Dept. of Agriculture, for suggestions in planning certain phases of the study.

A study of several methods of applying irrigation water to sugar beets was made at Fort Collins, Colorado, in 1931 and the results published (1).[3] The study was continued in 1932, and the results for the 2 years are presented in this report, which may be considered as a second progress report. As will be shown later, these 2 years were characterized by deficient precipitation, and while the differences between treatments may for that reason be greater than would be expected in years of normal or excess normal rainfall, the results obtained can definitely be assigned to the differences in irrigation practices since rainfall did not enter as an important factor in crop growth. For this reason it has seemed worthwhile to present the data and the conclusions drawn from the experiments at this time.

PREVIOUS WORK

Widtsoe and Stewart (12) reported the average results of 7 years' investigation on chemical composition of sugar beets. They conclude that there is a tendency for the percentage of sucrose to increase as more water is used, although in the data presented the trend is not consistent and the differences are small. The highest purity was obtained with intermediate applications up to 20 inches.

Harris (4) found the beets to be shorter in length on non-irrigated plats than on any of the plats irrigated up to 5 inches per week. The non-irrigated plats produced beets which were slightly lower in percentage of sucrose and purity, there being very little difference between the treatments in this respect. There was no correlation between the occurrence of "forked" beets and the method of irrigation used.

The results obtained by Harris and Pittman (5) indicate that larger yields can be obtained by applying water in several small rather than in a few larger irrigations. Weekly or alternate weekly small (2- or 3-inch) irrigations gave the largest yield of beets.

Pittman and Stewart (10) found that applications of water beyond 20 or 25 acre-inches usually gave little or no increase in the yield of sugar beets, potatoes, alfalfa, corn, or small grains.

Hemphill (6) and Fortier (3) reviewed duty of water experiments conducted on sugar beets. In one group of 61 fields in northern Colorado on which studies were reported, 11 produced more than 15 tons of beets per acre with 2.66 acre-feet of irrigation water and rainfall. At Loveland, Colorado, a 20.28-ton crop was produced on 2.15 acre-feet of water. Fortier concludes, "the requirement of sugar beets seems to vary from 1.6 to 2.5 acre-feet per acre."

Knorr (9) obtained the most satisfactory results by irrigating in moderate amounts and at such times as to keep the plants in good growing condition from time of thinning until about 3 weeks in advance of harvest.

[3] Reference by number is to "Literature Cited," p. 230.

Skuderna (11), from results obtained in experimental investigations and in statistical studies of farmers' fields, concluded that frequent light irrigations were relatively more important on light sandy soils than on heavier types. A final irrigation in early September resulted in an increased yield of beets over a late August final application in studies covering a 5-year period.

Jean (7) obtained results covering a 3-year period on irrigation practice with sugar beets. His studies indicate a decided advantage in favor of early as compared to late initial irrigation in the spring. He found no evidence of consistent lengthening of the roots due to late initial irrigation.

In studies conducted with wheat by Kezer and Robertson (8), it was found that irrigations of very small amounts (1 inch) distributed through the growing season gave the best results but were concluded to be impractical.

EXPERIMENTAL METHODS

The field planting was made early in the season, April 15 and 16, for the 2 years 1931 and 1932, respectively. The plats were 12 rows wide and 50 feet in length, the eight central rows only being harvested. The rows were 20 inches apart and the beets spaced 12 inches in the row through the use of a mechanical blocker. The plats were located on soil known as Fort Collins loam, light-textured phase, which is representative of the most important agricultural soil type in the Fort Collins area.

The treatments were repeated, using a random arrangement, making five plats of each treatment. In order to irrigate each plat as a unit, a temporary lateral ditch was cut through between each series of plats.

There was no attempt to measure the amount of water applied in 1931. The time used for each application, however, was adjusted so that each plat received the same number of hours of run during the irrigation season up to September 14. In addition, one method received a 1-hour late application of water on September 23, 1931, and September 25, 1932.

In 1932 the method used was very similar to that used in 1931 except that an attempt was made to measure the water used and to equalize the amount applied to the different treatments on the basis of the amount absorbed by the soil rather than on the basis of time of application. It was practically impossible to accomplish this without great expense by measuring the water applied to each plat in the experiment. A substitute plan was used in which a series of test plats were set up adjacent to the irrigation experiment. On these test plats it was planned to measure the amount of water applied and to obtain a relatively correct time of run necessary to equalize the total water applied on all plats by the end of the season. The plats in this test series were four rows wide and 50 feet in length, there being three plats of each treatment distributed at random. Wooden boxes equipped with metal headgates were used in each ditch to regulate the flow.

The results obtained in connection with the water measurements were rather variable and could only be used as a guide to the time of application necessary for the different treatments in order to equalize the amounts applied for the season. The plats used for these measurements were in all probability too small or with too few replications to obtain dependable results. They were discontinued after July 31 because of the anticipated shortage of water and the consequent need to make the most economical use of the supply available. The measurements made would indicate a possible total application during the growing season of some 2.5 to 3.0 acre-feet of water including rainfall. This estimate is based on the assumption that the measurements made represent the average amount of water applied in each irrigation during the season.

The treatments used were devised to determine (a) when to make the first application in the spring, (b) how often to apply the water, and (c) when to make the last application in the fall. The schedule for application of water as outlined and completed is given in Table 1.

TABLE 1.—*Schedule of applications of water.*

Treatment	Dates of irrigation*								No. of irrigations	Amount of water‡ at each irrigation in % of B
	June 15	July 1	July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 10	Sept. 25		
A	x	x	x	x	x	x	–	–	6	116.7
B	x	x	x	x	x	x	x	–	7	100.0
C	x	x	x	x	x	x	x	x	8	100.0
D†	x	–	x	–	x	–	x	–	4	200.0
E	–	x	x	x	x	x	x	–	6	116.7
F	–	–	x	x	x	x	x	–	5	140.0

*Dates of irrigation are approximate for the two years, the actual date of application never having varied more than 4 days from the approximate date.

†Only half of the usual application on Sept. 10, 1931, and on June 15, 1932, to equalize the total amount for this treatment with other treatments for the respective years.

‡The amount was on an arbitrary time basis in 1931 and from Aug. 15 to Sept. 25 in 1932, the time of run having been determined by actual measurement for the other dates in 1932.

In 1932 the time of run for the August 15 irrigation was reduced 20 minutes for each plat as an adjustment for a rainfall of 0.94 inch which occurred a few hours in advance of the irrigation.

The records of precipitation for an average of approximately 50 years and for the October to October periods for 1930–31 and 1931–32 are presented in Fig. 1.[4] It will be seen from this graph that the precipitation for the two years was generally lower than normal. The precipitation for the previous winter is important from the standpoint of the depletion of moisture reserves in the subsoil and the consequent need for early irrigation in the spring. From October, 1930, to May, 1931, inclusive, there was a deficit of 2.55 inches of rainfall, with an accrued additional deficit of 3.07 inches from June to Septem-

[4] Precipitation records were obtained from R. E. Trimble, Station Meteorologist, Colorado Agricultural College, with the exception of the records for August, 1932, which were recorded at the field station.

ber, 1931, inclusive. From October, 1931, to May, 1932, there was a deficit of 2.56 inches, while from June to September, 1932, there was a surplus of 1.10 inches. The normal or mean precipitation for some 50 years was 9.04 and 5.85 inches for these respective periods, making a mean total of 14.89 inches for the year.

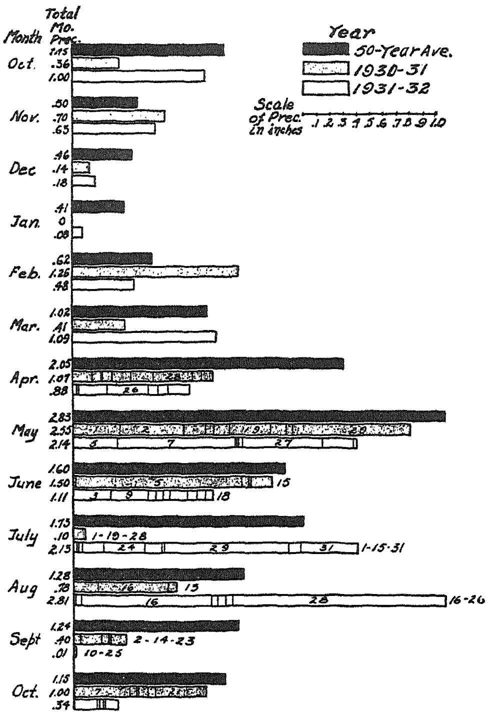

FIG. 1.—Precipitation by months for an average of approximately 50 years as compared to the October to October periods for 1930–31 and 1931–32. The precipitation for the growing period, April to October, is plotted by days, the day of the month being given for daily units of rainfall exceeding 0.25 inch. The day of the month when irrigation was applied is given at the end of the monthly bar.

In 1932 the plats were sampled on July 15, August 12, and September 9, 10 beets constituting the sample from each plat. Weights and sugar determinations were taken on each sample.

For harvest, all beets which had competition on all four sides were taken from the eight central rows of each plat for yield and sugar samples, the sugar samples consisting of two lots of 20 beets each. Each such sample was obtained so that it was representative of the entire plat. The yield in tons per acre was calculated on the basis of a perfect stand. The term "normally competitive" as used in this paper is applied to beets which have competition on four sides, the beets being spaced approximately to conform with the normal conditions for the plats. "Non-competitives" are beets which lack such competition on one or more sides.

The significance of differences was obtained through the use of the analysis of variance (2), the 5% point being taken as the level of significance. On this basis odds of 19 to 1 or more are considered significant.

EXPERIMENTAL RESULTS

The results obtained for the 10-beet samples which were taken from each plat on July 15, August 12, and September 9 are briefly summarized in Table 2 along with the average weight of 10 beets at harvest based on the weight of all competitive beets in the plat. The percentage of sucrose and refractometer values were obtained from

10-beet samples except on October 26–27 when two 20-beet samples were taken from each plat. In connection with the samples of 10 beets per plat taken on the three pre-harvest dates, it was not assumed that accurate plat values were to be obtained. With the average of the five plats considered, however, the larger differences should be of some significance.

TABLE 2.—*Summarized results for four sampling dates in 1932, the data being obtained from 10 beets per plat for the first three dates and from the remainder of the beets in each plat at harvest.*

Method	Weight of tops of 10 beets, lbs.				Weight of roots of 10 beets, lbs.			
	July 15	Aug. 12	Sept. 9	Oct. 26–27*	July 15	Aug. 12	Sept. 9	Oct. 26–27*
A	2.11	9.1	14.0	4.11	0.71	4.75	9.75	9.61
B	1.67	8.3	13.7	4.50	0.59	4.02	9.17	9.87
C	1.79	8.5	14.1	4.66	0.60	4.50	10.22	10.46
D	1.74	7.4	11.8	4.85	0.62	3.40	6.63	9.69
E	1.41	7.9	11.8	4.92	0.48	3.29	6.78	9.02
F	0.79	6.4	11.6	4.52	0.27	2.26	5.72	7.44
	Percentage of sucrose				Percentage of solids in juice			
	July 15	Aug. 12	Sept. 9	Oct. 26–27	July 15	Aug. 12	Sept. 9	Oct. 26–27
A	10.1	11.7	13.8	16.1	14.3	15.00	17.27	19.13
B	9.7	10.8	14.4	16.3	13.9	12.46	18.12	19.38
C	9.8	11.3	13.7	16.2	14.2	13.39	17.26	19.46
D	10.4	9.9	13.6	16.3	14.5	12.92	17.13	19.67
E	9.3	10.1	13.2	16.2	13.5	12.50	16.70	19.53
F	10.9	8.9	12.8	16.4	15.8	11.99	16.88	19.78

*The calculated average weight for a 10-beet sample based on the weight obtained for all beets in 10 plats.

The medium late and late first irrigation in the spring for the E and F plats, respectively, resulted in an irrecoverable loss in weight of the roots. It is also apparent that weight of tops, percentage of sucrose, and total percentage of solids in the juice were retarded on the same treatments, but that in each case the loss was only temporary and that by harvest time there was only a very slight difference for these characters between the different treatments. The B and C treatments are identical except for the one late application given C. The results obtained for the D treatment appear quite similar to those obtained for A.

All of the treatments, with the exception of A, have been carried out for the 2 years, 1931 and 1932. The A treatment was added in 1932. The results are summarized in Table 3. The standard errors for each year and as an average of the 2 years are given in Table 2 in "per cent of the mean" of all treatments. The difference required for significance (twice the standard error of a difference was taken as the minimum level of significance) is also given for each year and for the average of the 2 years' results.

The methods designated B and E are similar to those used in practice by the more successful growers, the average grower, how-

TABLE 3.—*Average of two years' results for*

Treatment	Tons of tops per acre			Tons of beets per acre			Sucrose, %		
	1931	1932	Ave.	1931	1932	Ave.	1931	1932	Ave.
A	—	5.31	—	—	12.17	—	—	16.1	—
B	14.60	6.48	10.54	21.52	12.53	17.03	14.4	16.3	15.4
C	15.85	7.09	11.47	22.35	13.34	17.85	14.7	16.2	15.5
D	15.71	7.34	11.53	18.58	12.12	15.35	14.1	16.3	15.2
E	16.11	7.44	11.78	20.11	11.32	15.72	14.5	16.2	15.4
F	13.10	6.91	10.01	16.59	9.41	13.00	15.1	16.4	15.8
Z	0.435	1.003	—	1.446	1.165	—	—0.039	—0.511	—
5% point	0.591	0.499	—	0.591	0.499	—	—	—	—
1% point	0.844	0.706	—	0.844	0.706	—	—	—	—
S. E. in %	5.36	4.29	3.43	2.74	3.56	2.25	2.60	1.04	1.40
Dif. for sig	22.8	0.82	1.07	1.54	1.19	1.00	1.07	0.48	0.61

*Results are for competitive beets only except for percentage stand where all beets in

†Pounds sucrose per acre indicated available is determined from pounds of beets per acre some indication of the relative production of extractable sucrose.

‡The length was taken from the crown of the topped beet to a point where the root was

ever, starting irrigation later than July 1 and making fewer and heavier applications. Early initial irrigation on June 15 for treatment B resulted in a somewhat greater yield of beets and total sucrose per acre than was obtained for E where the first application was delayed 2 weeks, the average differences for the 2 years being 1.31 tons of beets and 364 pounds indicated available sucrose. The differences are statistically significant using the 5% point level of significance.

In 1931 a delay of 4 weeks in making the first irrigation as shown by treatment F resulted in a loss of 4.93 tons of beets and 1,123 pounds indicated available sucrose per acre as compared with the B treatment. The differences in 1932 were 3.12 tons beets and 959 pounds sucrose, and as an average for the 2 years 4.03 tons of beets and 1,041 pounds sucrose per acre, respectively. Based on the yield of B the loss in tons of beets and pounds of sucrose per acre for treatment F amounted to 31.0% and 22.5%, respectively, for the 2 years. These results are in agreement with the findings of Jean (7) and support the present recommendations of sugar beet agriculturists for early initial irrigation.

Treatment C, receiving one late fall irrigation in addition to the same water given the other treatments, responded with increased tonnage of beets and sucrose content per acre, although the increases over treatment B are not large enough to be significant. There was apparently no consistent difference between B and C for either percentage of sucrose or coefficient of apparent purity. In both years the rainfall during September and October was relatively light, and harvest was delayed at least 3 weeks after the last application of water on the C treatment. The A treatment for 1932 shows a significantly lower yield than C. Skuderna (11) obtained similar results. It is recognized that following an irrigation or heavy rainfall there is *irrigation studies at Fort Collins, Colorado.**

Coef. apparent purity			Lbs. sucrose per acre indicated available†			1932 data		
1931	1932	Ave.	1931	1932	Ave.	Stand, %	Length of beet root, inches‡	Sprangled beet roots, %
——	91.6	——	——	3,598	——	82.6	8.1	30.8
88.6	91.6	90.1	5,490	3,751	4,621	79.9	7.9	27.5
88.8	90.8	89.8	5,820	3,928	4,874	78.6	8.4	24.4
87.5	89.9	88.7	4,574	3,557	4,066	79.4	8.0	32.5
89.4	89.8	89.6	5,198	3,315	4,257	80.2	7.7	29.2
88.2	90.4	89.3	4,367	2,792	3,580	79.6	7.3	29.2
—0.431	0.565	—	1.102	0.937	——	——	—0.071	——
——	0.499	—	0.591	0.499	——	——	——	——
——	0.706	—	0.844	0.706	——	——	——	——
1.20	0.50	0.65	3.99	4.48	3.00	3.50	5.51	——
3.01	1.28	1.65	574	442	363	7.9	1.2	——

the plat were considered.

x percentage ot sucrose x coefficient of apparent purity. For comparative purposes it gives

one-quarter inch in diameter.

often a temporary depression in percentage of sucrose and purity. For that reason the harvest should be delayed at least 2 or 3 weeks after the last application of water.

There was a marked difference in the comparative results obtained from treatment D for the 2 years, the yield of roots in 1931 being 2.94 tons less than B and in 1932 only 0.41 ton less than B. As an average for the 2 years, the infrequent irrigation on D resulted in a slight, although significant, loss in both tonnage of roots and sucrose production per acre. These results, particularly for 1931, are in accord with the results obtained for sugar beets by Harris and Pittman (5) and for wheat by Kezer and Robertson (8).

As an average for the 2 years, none of the differences between treatments, for either percentage of sucrose or coefficient of apparent purity are statistically significant.

The differences between treatments for length of root are not large enough to be statistically significant. There appears to be some relation, however, between length of root and the tonnage yields. In any case, the data fail to support a rather popular belief among growers that late initial application in the spring is conducive to production of long roots.

The results recorded for "sprangling" are of doubtful significance and are similar in this respect to results obtained by Harris (4). The differences recorded do not appear to be correlated with any early differences in the treatment given.

SUMMARY AND CONCLUSIONS

The results of 2 years' studies of different methods of irrigation at Fort Collins, Colorado, are presented. The experiment sought information on time for first irrigation in the spring, frequency of application, and time for last application in the fall.

Under conditions of unusually deficient rainfall as existed during the 2 years in which this experiment was conducted, it seems probable that the differences may have been somewhat greater than would be expected in a year having normal rainfall or abnormally heavy rainfall. The conclusions which appear justified for the data presented must be considered only in relation to this fact. The results obtained, while preliminary, should be of distinct value as a guide to irrigation practice, particularly in those years following a winter of deficient rainfall.

The largest yield was obtained both years for treatment C with a very early (June 15) first application and a very late (September 25) last application, the applications being made at bi-weekly intervals during the summer. The C treatment averaged 17.85 tons of beets for the 2 years as compared with 17.03 tons for treatment B which received similar treatment without the late application in September. This difference is not quite great enough to be considered statistically significant. There was no difference in quality of the beets from the two treatments.

Infrequent irrigation on treatment D resulted in a decreased yield as compared to treatment B of 1.68 tons beets and 555 pounds indicated available sucrose per acre as an average for the 2 years, the differences being statistically significant.

Early first application (treatment B) resulted in a slightly significant increase of 1.31 tons of beets and 364 pounds indicated available sucrose per acre over medium late (treatment E). As compared with late first irrigation (treatment F), the B treatment resulted in an increase of 4.03 tons of beets and 1,041 pounds sucrose per acre as an average of the 2 years.

The quality of the beets as indicated by percentage of sucrose and coefficient of apparent purity was not significantly affected by any particular treatment.

The length of beet appears to be correlated to some extent with weight rather than with any particular time of first irrigation, although the differences between treatments are not statistically significant. In any case these data do not support the popular belief among growers that a delay in the first irrigation results in longer and better shaped beet roots.

Under the conditions of this experiment a desirable irrigation practice with sugar beets would appear to consist of early initial application in the spring followed by rather frequent light applications and a relatively late application in the fall.

LITERATURE CITED

1. BREWBAKER, H. E. Sugar beet irrigation studies. Facts About Sugar, 28: 93–94. 1933.
2. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1932.
3. FORTIER, SAMUEL. Irrigation requirements of the arid and semi-arid lands of the Missouri and Arkansas River Basins. U. S. D. A. Tech. Bul. 36. 1928.
4. HARRIS, F. S. The irrigation of sugar beets. Utah Agr. Exp. Sta. Bul. 146. 1917.
5. ———— and PITTMAN, D. W. Irrigation experiments with sugar beets. Utah Agr. Exp. Sta. Bul. 186 1923.

6. HEMPHILL, R. G. Irrigation in northern Colorado. U. S. D. A. Bul. 1026. 1922.
7. JEAN, F. C. The development of root systems of sugar beets under the conditions of early and late initial irrigation. Abst. in Jour. Colo.-Wyo. Acad. Sci., 1: No. 4, 14–15. 1932.
8. KEZER, A., and ROBERTSON, D. W. The critical period of applying irrigation water to wheat. Jour. Amer. Soc. Agron., 19: 80–116. 1927.
9. KNORR, F. Irrigated field crops in western Nebraska. Nebr. Agr. Exp. Sta. Bul. 141. 1914.
10. PITTMAN, D. W., and STEWART, GEORGE. Twenty-eight years of irrigation experiments near Logan, Utah. Utah Agr. Exp. Sta. Bul. 219. 1930.
11. SKUDERNA, A. W. Annual Report Research Department. American Beet Sugar Company. 1928.
12. WIDTSOE, J. A., and STEWART, R. The chemical composition of crops as affected by different quantities of irrigation water. Utah Agr. Exp. Sta. Bul. 120. 1912.

THE EFFECT OF NITROGENOUS FERTILIZERS ON THE GROWTH OF LAWN GRASSES[1]

J. W. ZAHNLEY AND F. L. DULEY[2]

Until very recent years but little attention has been given to the use of commercial fertilizers for grass in Kansas or regions of similar climatic conditions. There has developed, however, an increasing interest in the use of these materials for treating lawns. A considerable number of people are using them and the tests so far have indicated that they can be substituted for manure. Commercial fertilizers are popular because they do not introduce weed seed or make the lawn unattractive with litter as is often the case with manure. In 1925 a series of tests was begun at the Kansas Experiment Station in cooperation with the United States Golf Association Green Section in which studies were made on the adaptation of different grasses as well as the effect of nitrogenous fertilizers in improving the turf produced by each.

METHODS

The soil was Wabash silt loam, a bottom soil at the foot of a slope on the college campus. The fertilizer treatments were applied across parallel strips of Kentucky bluegrass, Washington bent, and German mixed bent grasses. The plats thus formed were 10 x 10 feet in size. The amount of fertilizer used for each application per plat was adjusted to the equivalent of the nitrogen contained in 10 ounces of ammonium sulfate. This provided for an application of 4.4 ounces of urea and 13.2 ounces of sodium nitrate, or approximately 272 pounds of ammonium sulfate, 120 pounds of urea, and 359 pounds of sodium nitrate per acre at each application. The fertilizer was dissolved in water and applied with a sprinkling can. Six applications were made each season at intervals of 4 to 5 weeks beginning in the latter half of March. The total fertilizer applied per acre throughout the season, therefore, amounted to 1,633 pounds of ammonium sulfate, 718 pounds of urea, and 2,156 pounds of sodium nitrate. The grass received copious amounts of irrigation water applied by overhead sprinkling.

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[2] Associate Professor of Farm Crops and Professor of Soils, respectively.

The effects of the fertilizers during the first 3 years of these tests were determined mainly by observation. In 1928 weights were taken of the grass produced, but the treatments up to that time had not supplied exactly the same quantity of nitrogen in the various fertilizers. In 1929 and 1930 this discrepancy was corrected and, for this reason, only the weights obtained during these 2 years are considered in the averages. In obtaining weights the clippings were collected from the lawn mower, spread out in the greenhouse, and dried. The weights reported are on air-dry material.

RESULTS

The effect of the various fertilizers are shown in Table 1. It may be seen from this table that the yield was greatly increased wherever nitrogenous fertilizers were applied. There have been no great differences in favor of any particular fertilizer, but where compost was added to ammonium sulfate the yield was somewhat higher. In this case the amount of nitrogen as well as other plant foods contained in the compost was in excess of that applied on the plat receiving ammonium sulfate alone. Urea also gave slightly higher yields than sodium nitrate or ammonium sulfate, but the difference was not great, although it was apparent with all three grasses. Owing to the fact that urea was found to get into bad physical condition, it was not as easily spread as the other materials. This would tend to offset any slight advantage which it might show in yield.

TABLE 1.—*Effect of soil treatments on the yield of different grasses.*

Treatment	Yield, lbs. per acre				
	1928	1929	1930	Ave., 1929–30	Relative yields
Kentucky Bluegrass					
No treatment	1,465	2,363	2,831	2,597	100
Sodium nitrate	1,875	6,096	5,894	5,995	231
Ammonium sulfate	1,731	5,997	6,424	6,210	240
Ammonium sulfate and compost	2,088	6,731	6,713	6,722	259
Urea	——	7,111	5,723	6,417	247
Washington Bent Grass					
No treatment	541	964	1,377	1,170	100
Sodium nitrate	1,756	4,126	3,981	4,053	346
Ammonium sulfate	1,684	4,020	3,724	3,872	331
Ammonium sulfate and compost	2,469	4,814	5,047	4,930	421
Urea	——	5,556	3,590	4,573	391
German Mixed Bent Grass					
No treatment	1,354	3,060	3,817	3,438	100
Sodium nitrate	2,072	5,009	5,223	5,116	149
Ammonium sulfate	2,151	4,639	5,460	5,049	147
Ammonium sulfate and compost	2,508	6,386	6,430	6,408	186
Urea	——	6,108	5,606	5,857	170

On all of the fertilized plats there was a more dense turf with fewer weeds and less white clover than was to be found on the untreated plat.

On another set of three plats, tests were made to determine the effect of different rates of application of ammonium sulfate on the stand and growth of grass. The rate of application varied from 5 ounces per plat, or 135 pounds per acre, to 15 ounces per 100 square feet, or 408 pounds per acre. These rates were applied three times during the seasons of 1930 and 1931. Even this heavy amount, 1,224 pounds for the year, had no detrimental effects and produced an excellent, uniform turf with practically no weeds present. The number of dandelions in the different plats were counted with the results shown in the last column of Table 2. This difference in the growth of dandelions is also evident in Fig. 1.

TABLE 2.—*Effect of different rates of application of ammonium sulfate on the yield of Kentucky bluegrass.*

Rate of application		Yield per acre, lbs.				No. of dandelions per plat
Per acre	Per plat	1930	1931	Ave., 1930–31	Relative yields	
None.	None.	2,831	—*	2,831	100	—
135...	5 oz. per 100 sq. ft.†...	3,615	3,147	3,381	119	18
270...	10 oz. per 100 sq. ft.†...	5,466	4,784	5,125	181	5
408...	15 oz. per 100 sq. ft.†...	7,327	6,034	6,680	237	2

*The plat used as check in 1930 was discontinued.
†These applications were made three times during the season.

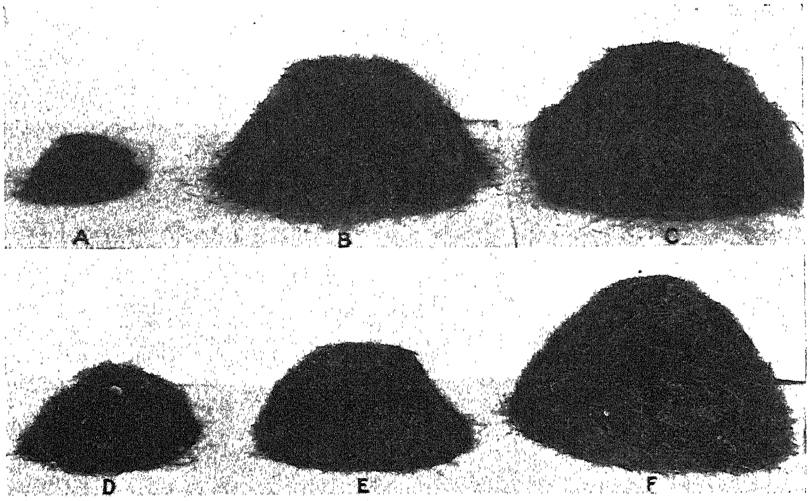

FIG. 1.—Bluegrass clippings from plats 100 square feet in area. A, no treatment; B, sodium nitrate; C, ammonium sulfate; D. Ammonium sulfate, 5 oz. per plat, note dandelions; E, ammonium sulfate, 10 oz.; F, Ammonium sulfate. 15 oz. Very few dandelions grew in heavily fertilized plats.

It would seem from these results that one of the best methods of preventing the growth of dandelions is to produce such a dense growth of grass that the dandelion seedlings do not become readily established and their growth is greatly retarded due to competition with the grass. The competition is further increased by high cutting of the grass which will tend to shade the ground and retard the development of weeds of various kinds, especially during the seedling stage.

SOIL REACTION

It is sometimes assumed that the control of weeds by fertilizers may be due in large measure to a change in soil reaction. Tests made on these plats show that the reaction has not been greatly affected by the fertilizer treatments. The surface soil treated with ammonium sulfate was only slightly acid with a pH value of 6.5. This is probably due to the fact that this soil contains a high amount of replaceable basic material. Table 3 shows the pH values determined on two dates. The colorimetric method was used in 1928 and the quinhydrone method in 1933.

TABLE 3.—*Effect of nitrogenous fertilizers on soil reaction.*

Treatment	Depth, in.	pH value	
		March, 1928	Feb., 1933
Check	0–3	7.3	8.2
Check	4–7	7.3	8.1
Ammonium sulfate	0–3	7.1	6.5
Ammonium sulfate	4–7	7.2	7.3
Sodium nitrate	0–3	—	8.3
Sodium nitrate	4–7	—	8.2

SUMMARY

Tests were conducted at the Kansas Agricultural Experiment Station during the years 1925 to 1930 with different nitrogenous fertilizers on Kentucky bluegrass, Washington bent, and German mixed bent grasses.

Ammonium sulfate, sodium nitrate, and urea were about equally effective when used at such rates that equivalent amounts of nitrogen were supplied. However, there was a slight advantage for urea with each grass.

The combined treatment of ammonium sulfate and compost gave a slight increase over urea. This was probably due to the additional plant food supplied in the compost.

Applications as high as 1,633 pounds of ammonium sulfate or 2,156 pounds per acre of sodium nitrate during the season were used without injury to the grasses. This was supplied in six applications.

The number of dandelions was greatly reduced by the use of heavy applications of ammonium sulfate. This is thought to be due to increased competition by the grass due to greater growth resulting from the fertilizer application.

The pH value of this soil has not been greatly affected even by these heavy fertilizer treatments. The ammonium sulfate, however, has tended to make the soil slightly acid.

EFFECTS OF APPLICATIONS OF NITRATE OF SODA UPON THE YIELDS OF TIMOTHY HAY AND SEED[1]

Morgan W. Evans[2]

Of the three chemical elements which are commonly applied to the soil in the form of commercial fertilizers, nitrogen usually produces much larger increases in the yields of timothy hay than phosphorus or potassium (4).[3] Usually, the largest increases in hay yields may be obtained from applications of nitrate of soda or some other nitrogen-carrying fertilizer in combination with either one or both of these mineral elements (2, pages 50–52). The increased yields of hay in meadows where phosphorus or potassium have been applied are often due, in part at least, to their effect upon the clover growing in the meadow.

In an experiment conducted at Aberystwyth, Wales, to determine the effects of different fertilizers upon the yields of timothy seed, Evans and Calder (3) found that nitrogen had the most marked effect on seed production, phosphates and potash applied together or with nitrogen added having a negligible influence. At the Rhode Island Agricultural Experiment Station, Gilbert (6, page 36) found that the largest yields of seed of Rhode Island bent grass were obtained from those plats on which fertilizers containing large proportions of nitrogen were applied.

While a considerable number of experiments have been conducted for the purpose of determining the effects of fertilizers upon the yields of timothy hay, only a few have been reported in which the effects of the fertilizers upon seed yields have been studied. It was for the purpose of obtaining additional information in regard to the effects of nitrogenous fertilizers upon the yields of timothy seed, and the way in which these effects compare with the effects of the same application of fertilizers upon the yields of timothy hay, that the present experiment was planned and conducted.

Nitrate of soda was used as the nitrogen carrier. The soil on which the experiment was conducted has been classified as Caneadea clay loam.

DESCRIPTION OF EXPERIMENT

The experiment was conducted in 1924, 1925, and 1926. The three series of plats were all located in the same meadow of Huron timothy—a variety which blooms and matures about 6 days later than ordinary timothy. In 1924 and 1925, the plats used contained 0.0231 acre each, while in 1926 each one contained 0.01155 of an acre. The dates of application of the nitrate of soda were May 10, 1924; May 6, 1925; and May 1, 1926. In each series, the rates of application were 40, 80, 160, and 320 pounds per acre. No nitrate was used in the

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[1] Contribution from the Timothy Breeding Station conducted cooperatively by the Office of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Ohio Agricultural Experiment Station, at North Ridgeville, Ohio. Received April 24, 1933.

[2] Associate Agronomist.

[3] Reference by number is to "Literature Cited," p. 240

check plats. Six plats were fertilized at each rate, and from three of them hay yields and from the other three seed yields were obtained. The plats used for seed production alternated with those from which hay was harvested.

RESULTS

The average yields of hay from the triplicate plats under each treatment are summarized in Table 1 and the average yields of seed from triplicate plats in Table 2. In Fig. 1, these hay and seed yields are shown graphically.

TABLE 1.—*Yields per acre of air-dry timothy hay in 1924, 1925, and 1926 in plats on which nitrate of soda was applied at different rates per acre.*

Application of nitrate of soda per acre, lbs.	Yield per acre, tons (2,000 lbs.)				Relative yields with check as 100
	1924	1925	1926	Ave.	
0	1.73	0.77	1.27	1.26	100
40	1.93	0.84	1.43	1.40	111
80	2.01	0.96	1.54	1.50	119
160	2.23	1.05	1.88	1.72	137
320	2.46	1.10	2.06	1.87	149

TABLE 2.—*Yields per acre of timothy seed in 1924, 1925, and 1926 in plats on which nitrate of soda was applied at different rates per acre.*

Application of nitrate of soda per acre, lbs.	Yield per acre, bushels (45 lbs.)				Relative yields with check as 100
	1924	1925	1926	Ave.	
0	3.78	1.58	3.57	2.97	100
40	4.68	1.57	4.98	3.74	126
80	5.12	2.13	5.96	4.40	148
160	6.07	2.48	6.55	5.03	169
320	5.72	2.86	8.65	5.74	193

RELATION OF SPRING RAINFALL TO YIELDS

The records in Tables 1 and 2 show that the effects of nitrate of soda upon the yields of both hay and seed varied quite widely in different years. These variations are evidently largely dependent upon the amount of rainfall during the spring months. The rainfall records for April, May, and June in each of the 3 years in which this experiment was conducted, and also the 60-year average rainfall in these months, at the U. S. Dept. of Agriculture Weather Bureau Station at Cleveland, Ohio, located at a distance of about 20 miles from and at about the same elevation as the Timothy Breeding Station, are presented in Table 3.

Tables 1 and 3 show that the yields of hay were closely correlated with the total rainfall during April, May, and June. The yields of seed (Table 2), however, were somewhat greater in 1926, when the rainfall was slightly below normal, than in 1924, when it was con-

TABLE 3.—*Spring rainfall in 1924, 1925, and 1926 compared with the 60-year average.*

Year	Rainfall, inches			
	April	May	June	Total
1924	2.85	2.62	5.73	11.20
1925	1.37	2.24	1.81	5.42
1926	3.44	1.48	2.58	7.50
Ave. 1871–1930	2.48	3.06	3.26	8.80

siderably above normal. The smaller yields in 1924 than in 1926 may be attributed, in part, on the plats fertilized at the rates of 160 and 320 pounds per acre to the fact that the timothy stems lodged to some extent before the seed was mature. The smaller yields of seed in 1924, however, apparently were not entirely due to this factor, since in the plats fertilized at the rates of 40 and 80 pounds of nitrate of soda per acre in which no lodging occurred, the yields of seed were also greater in 1926 than in 1924—the season with the largest rainfall. The distribution of the rainfall during these 3 months may have had an important influence. In 1925, when the rainfall was below normal in each one of the 3 spring months, the yields of both hay and seed were relatively low.

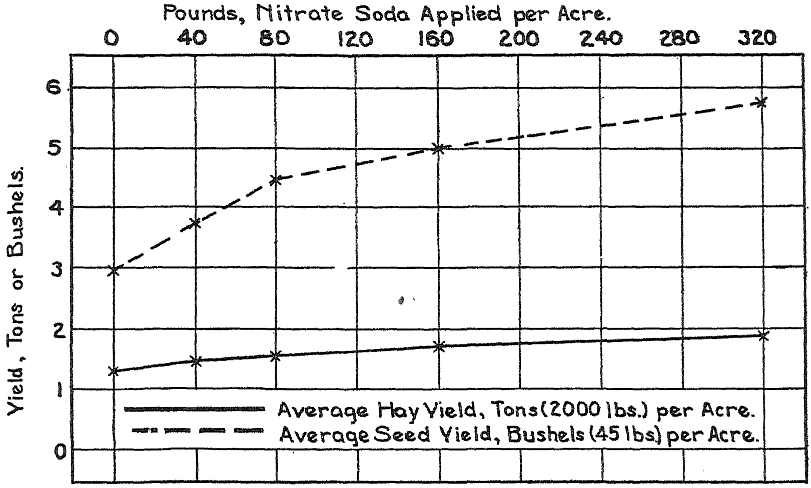

FIG. 1.—Average results of applications of nitrate of soda upon the yields of timothy hay and seed in 1924, 1925, and 1926.

EFFICIENCY OF DIFFERENT RATES OF APPLICATION OF NITRATE OF SODA

As the quantity of nitrate of soda applied per acre increased, the yields of both hay and seed increased. These increases in yields, however, were not as great in proportion to the amount of fertilizer used where it was applied at the heavier as where it was applied at the lighter rates. This result (Table 4) illustrates the operation of the economic law of diminishing returns (5, page 64).

TABLE 4.—*Average increase in yield of timothy hay and seed in 1924, 1925, and 1926 for each pound of nitrate of soda applied to the soil.*

Pounds of nitrate of soda per acre	Increase in yield for each pound of nitrate of soda applied, lbs.	
	Hay	Seed
40	7.0	0.86
80	6.1	0.80
160	5.8	0.58
320	3.8	0.39

RELATIVE EFFECTS OF NITRATE OF SODA UPON YIELDS OF HAY AND SEED

The relative yields of hay and of seed from plats on which nitrate of soda had been applied to the soil at different rates have been shown in Tables 1 and 2. For each rate of application of the fertilizer, the increase in the yield of seed was greater than the increase in the yield of hay. In plats where 80 pounds of nitrate of soda per acre were applied, the yield of seed was 148% of the yield of seed from the unfertilized plats, while an application of 320 pounds per acre of nitrate was required for an approximately equal percentage increase in the yield of hay. Except on the plats fertilized at the rates of 160 and 320 pounds of nitrate of soda per acre in the year with the heaviest rainfall, there were no indications that the plants were making a large vegetative growth at the expense of seed production.

The results of this experiment substantially agree with those obtained in an experiment conducted by Blair (1, pages 55–56) with timothy at the Dominion Experimental Farm at Kentville, Nova Scotia, Canada. There, the yields of both hay and seed were increased as the result of applications of 150 pounds of nitrate of soda per acre—the increase in seed yield being much greater than the increase in hay yield.

EFFECTS OF NITRATE OF SODA IN RELATION TO AMOUNT OF AVAILABLE NITROGEN IN SOIL

Kraus and Kraybill (7) state that tomato plants grown with an abundant supply of available nitrogen and the opportunity for carbohydrate synthesis are vigorously vegetative and unfruitful, while plants grown at first with an abundant supply of nitrogen and then transferred and grown with a moderate supply of available nitrogen are less vegetative but more fruitful. These authors also conclude that fruitfulness is associated neither with the highest nitrates nor highest carbohydrates but with a condition of balance between them.

Thorne (10, pages 294, 300–311) found in an experiment extending over a period of 30 years that when corn, oats, and wheat were grown in a 5-year rotation in which one crop of clover and one of timothy were also included, the increases of both grain and of stover or straw were so small that they were not profitable. He concluded that, under the conditions of this experiment, a large proportion of the available nitrogen needed for the growth of the cereal crops was derived from that added to the soil by the clover growing in the same rotation.

That the degree to which the growth of any crop responds to applications of nitrogenous fertilizers on the soil depends upon the quantities of available nitrogen already in the soil is indicated by the results of an investigation with timothy conducted by Newton and Ficht (9, pages 21–34) at the University of Alberta at Edmonton, Canada. They found that in plats of timothy ranging from 1 to 5 years old, the total quantity of nitrogen in the soil was practically the same in the plats of all ages. On the other hand, the quantity in the form of nitrates, i. e., the form of nitrogen available to plants, decreased as the plats became older. In the 1-year-old plats there were 3.8 p. p. m. of nitrate nitrogen on May 4 and 3.4 parts on July 6; in the 3-year-old plats there were 2.0 and 1.6 p. p. m. of nitrate nitrogen, respectively, on these two dates; while in the 5-year-old plats there was only a mere trace of nitrates on both dates. The yields of timothy hay were very closely correlated with the amounts of nitrates in the soil.

The results reported by Newton and Ficht are supported by those obtained by Lyons and Bizzell (8), who found relatively small quantities of nitrogen in the form of nitrates in soils producing timothy.

The plats used in the experiment which was conducted at the Timothy Breeding Station in 1924, 1925, and 1926 were located on land which had been in timothy continuously for from about 5 to 7 years. It may be assumed that the quantity of nitrogen in the soil in forms available to plants had become depleted and that when the nitrate of soda was applied it restored available nitrogen in quantities needed for the nutrition of the plants and for the production of both hay and seed.

SUMMARY

Applications of nitrate of soda were made in 3 seasons on a timothy meadow which was approximately 5 to 7 years old for the purpose of determining the comparative effects of the fertilizer upon the yields of hay and seed. The nitrate was applied at the rates of 40, 80, 160, and 320 pounds per acre, no nitrate being applied on the check plats.

The effects of the nitrate upon the yields of hay and seed varied with the rainfall in April, May, and June. In the season with a low rainfall, the yields of both hay and seed were also low. The greatest yields of hay were obtained in the season with the greatest spring rainfall. The yields of seed were somewhat larger in the season when the spring rainfall was slightly below normal than in the season when the total rainfall in April, May, and June was about 27% above normal.

As the rate of application of nitrate of soda was increased from 40 to 320 pounds per acre, there was a gradual decrease in the additional amount of hay and of seed produced for each pound of fertilizer used.

For each rate of application of the fertilizer, the resulting increase in the yield of seed was greater than the corresponding increase in the yield of hay. Under the conditions of this experiment, except on the plats fertilized at the two heaviest rates in the season with the greatest spring rainfall, there was no tendency for the timothy plants to make a vigorous vegetative growth at the expense of seed production.

The high degree of effectiveness of the nitrate of soda in increasing the yields of timothy hay and seed in this experiment may be attributed largely to the small quantities of nitrogen in a form available for plants, usually occurring in soils which have produced timothy for several years.

LITERATURE CITED

1. Blair, W. S. Dom. Expt. Farms. Expt. Sta. Kentville, N. S., Rpt. Supt., 1923: 55–56. 1925.
2. Brooks, W. P., Fulton, E. S., and Gaskill, E. F. Report of the Agriculturist. 19th An. Rpt. Mass. Agr. Exp. Sta., 23–60. 1907.
3. Evans, G., and Calder, R. A. Manuring pedigree grasses for seed production. Welsh Jour. Agr., 7: 105–208. 1931.
4. Evans, Morgan, W. Fertilizing timothy meadows with nitrate of soda. Ohio Agr. Exp. Sta. Bimonthly Bul. 143: 44–49. 1930.
5. Fetter, F. A. The Principles of Economics. New York: Century Company. 1904.
6. Gilbert, B. E. Forty-third Annual Report of the Director. R. I. Agr. Exp. Sta. 43rd Ann. Rpt., 36. 1931.
7. Kraus, E. J., and Kraybill, H. R. Vegetation and reproduction with special reference to the tomato. Ore. Agr. Exp. Sta. Bul. 149. 1918.
8. Lyon, T. L., and Bizzell, J. A. Some relations of certain higher plants to the formation of nitrates in soils. Cornell Univ. Agr. Exp. Sta. Mem. 1. 1913.
9. Newton, R., and Ficht, J. Experiments with timothy. Alberta Res. Bul. 3. 1926.
10. Thorne, C. E. The maintenance of soil fertility. Ohio Agr. Exp. Sta. Bul. 381: 243–354. 1924.

ADAPTABILITY AND ACCURACY OF THE EMERSON LIME ANALYZER FOR TESTING THE NEUTRALIZING VALUE OF VARIOUS LIMING MATERIALS IN V[illegible]GIN[illegible][1]

N. A. Pettinger and R. L. Selby[2]

The recent appearance of the Emerson lime analyzer in portable kit form gives considerable promise of fulfilling a long-felt need for equipment that is suited to analyzing liming materials under field conditions by non-technical workers. Ever since liming materials have come into general use, vendors of such materials have been obliged to submit one or more samples to a chemical laboratory for analysis, when information was desired concerning the value of their products for liming purposes. In some cases this has entailed considerable effort, inconvenience, expense, and delay. Much of the delay and inconvenience in obtaining the information sought after, might have been avoided if portable field equipment had been available which could be depended upon to give accurate results. Where it has been necessary to submit many samples for analysis, such equipment might effect a financial saving also.

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[2] Associate Agronomist and Assistant, respectively.

Before any equipment can be of much service it must be sufficiently accurate and consistent in performance to make its use practicable in the work for which it was made. Hence, if the Emerson lime analyzer is to come into wide usage, it must first of all be able to determine the acid neutralizing power of liming materials fairly accurately, as judged by the results obtained in the chemical laboratory. Of course speed, convenience, and cost will also have some effect on the extent to which this equipment will be used eventually, but accuracy is, of necessity, the first requisite to establishing confidence in the results obtained. The present paper contains the results obtained at the Virginia Experiment Station in a study of the accuracy and convenience of the Emerson analyzer as compared with a commonly used laboratory procedure for determining the neutralizing value of various liming materials.

MATERIALS AND METHODS

In order to determine the range of usefulness of the Emerson analyzer, 42 samples of different calcic and magnesic materials were collected for analysis from different parts of the United States. Most of these samples were of materials that are commonly used for liming purposes. The collection included 3 samples of freshly burnt lime, 10 samples of hydrated lime, 3 samples of air-slaked lime, 12 samples of ground limestone, 3 samples of marl, 4 samples of oyster shells, and a miscellaneous collection of 7 samples of which 6 were of various calcic and magnesic minerals and 1 of wall plaster (Table 1). Although a majority of the samples were collected in Virginia, some of them came from such distant states as Florida, Texas, Arizona, Washington, Utah, Montana, Wisconsin, Michigan, Illinois, Ohio, New York, and Pennsylvania.[3]

The laboratory procedure used as a standard by which to judge the accuracy of the Emerson analyzer is the tentative method of the Association of Official Agricultural Chemists for determining the neutralizing value of agricultural liming materials.[4] Although the official method reports the results for burnt and hydrated limes as percentage of calcium oxide and for limestones and marls as percentage of calcium carbonate equivalent, for the sake of uniformity all of the results are reported here as percentage of calcium carbonate equivalent.

The Emerson equipment was used as directed by the manufacturer except in the case of burnt, hydrated, and air-slaked limes. Although the tests were made in a laboratory, no use was made of available laboratory equipment, such as bunsen burners, balances, burettes, etc. In testing the burnt, hydrated, and air-slaked limes, however, it was necessary to change the procedure for weighing the samples for analysis. These materials, after being pulverized sufficiently fine for testing, were so fluffy that it was practically impossible to place a gram of any of them in the hydrometer pan supplied by the manufacturer. Attempts to heap the sample above the hydrometer pan usually resulted in some of the material sliding off into the submerging liquid (water), a portion of which invariably lodged on the shoulders of the enlarged part of the hydrometer. Two possibilities for error were thus introduced, *viz.*, (1) the adhering particles increased the weight of the hydrometer, and (2) since the oxides and hydroxides of calcium and magnesium are slightly soluble in water, the density of the submerging liquid was increased. Although the errors thus introduced tend to compensate each other, the net error is never known, and it was therefore not possible to use the Emerson equipment as sold by the manufacturer for testing the fluffy types of lime.

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[3] The writers are indebted to Dr. R. J. Holden of the Geology Department, Virginia Polytechnic Institute, for 25 samples; and to Professor F. H. Fish of the Chemistry Department, Virginia Polytechnic Institute, for 2 samples.

[4] Official and tentative methods of analysis of the Association of Official Agricultural Chemists. Compiled by the committee on editing methods of analysis. Washington, D. C.: Association of Official Agricultural Chemists. Ed. 3. 1930.

The weighing device was then modified as follows: A piece of thin cardboard paper about 1 inch square was placed on the hydrometer pan furnished by the manufacturer. A weighing pan approximately three times larger than the hydrometer pan was then fashioned out of thin aluminum sheet metal and placed on the cardboard paper. This improvised pan was molded into the shape of the halves of a football cut from end to end through the center, being 35 mm long, 25 mm wide at the top (center), 12 mm deep (center), and weighed approximately 1 gram. The ends were tapered to facilitate transferring the sample to the reaction tube. The additional weight of the paper and improvised weighing pan caused the hydrometer to sink to the extent that the graduations in the stem came to rest below the surface of the submerging liquid (water). Hence, it was necessary to make up and use a salt solution of such density as would allow the hydrometer to float at the proper height when carrying the additional weight. Potassium chloride was the salt used in the tests reported here with burnt, hydrated, and air-slaked limes. Thus modified, the samples were weighed in the same manner as for the other types of lime with the equipment used as directed by the manufacturer.

The samples for the official method were weighed on a laboratory torsion balance having a sensitivity of approximately 4 milligrams.

RESULTS

The results obtained by the two methods of analysis are given in Table 1. Considering first the averages for the different groups of materials, it may be noted that the average $CaCO_3$ equivalents for five of the seven groups differ by less than 1%. The other two groups show average differences of 1.01% and 1.25%, respectively.

A detailed study of the individual samples shows approximately the same variations between the two methods as are shown by the group averages. Thus, 27 of the 42 samples show differences of less than 1% $CaCO_3$ equivalent, 9 samples differed between 1% and 2%, 3 samples by more than 2% but less than 3%, and 3 samples failed to check by more than 3%. A part of the large variation shown by one sample in each of the last three groups may have been due to the fact that the samples were of a blackish color, making the end point very uncertain. These data show that the values obtained by the two methods differed by less than 1% $CaCO_3$ equivalent in 64% of the total number of samples tested, by less than 2% $CaCO_3$ equivalent in 86% of the tests, by less than 3% $CaCO_3$ equivalent in 93% of the tests, and by less than 4% $CaCO_3$ equivalent in 100% of the tests. The average difference between the two methods for all samples is 1.06% $CaCO_3$ equivalent.

It is also of interest to note from the data in Table 1 that the duplicate determinations made with the Emerson equipment show more variation than those made by the official method. Thus, only 2 of the 42 samples show variations of more than 1% $CaCO_3$ equivalent between duplicate determinations when tested by the official method, whereas the duplicate determinations by the Emerson method failed to check closer than 1% $CaCO_3$ equivalent in 17 of the 42 samples. The average difference between duplicates by the official method is 0.39% $CaCO_3$ equivalent and by the Emerson method 0.77%. Outside of the ground limestone samples, where the duplicates by the Emerson method checked better than for any other group of samples, the average difference between duplicates by the Emerson method is 1.04% $CaCO_3$ equivalent. The greater variability in the results obtained by the Emerson method is to be expected when the nature of the weighing device and the coarse graduations on the reaction tube are considered.

As a matter of personal interest records were kept of the time required to test the various samples by each method. The data obtained appear to be of sufficient interest to warrant presentation and are therefore included in Table 1. The data show that samples which tested 100% $CaCO_3$ equivalent or higher required less total time by the Emerson method than by the official method when duplicate determinations were made. The principal reason for this is that it is not necessary to cool the samples after boiling in the Emerson procedure, whereas the official method requires that the samples be cooled regardless of their composition. Cooling usually required from 5 to 8 minutes. However, for samples which tested less than 100% $CaCO_3$ equivalent the Emerson method was slower than the official method. The reason for this difference is twofold, *viz.*, (1) the additional time required for cooling the samples, and (2) the duplicate samples must be cooled at different times in the Emerson method, while in the official method they may be cooled either simultaneously or one sample may undergo cooling while its duplicate is being carried through some other part of the procedure. The data show, therefore, that burnt limes (from rock or oyster shells), hydrated lime, air-slaked lime, and the higher-grade dolomitic limestones may be tested more quickly with the Emerson equipment, but that marls, unburnt oyster shells, ground limestone, and the lower-grade dolomitic limestones may be tested more quickly by the official method.

In cases where it is considered that duplicate determinations are

TABLE 1.—*Analyses of various calcic and magnesic substances by the*

Sample No.	Material tested	Source	Time required, minutes			
			Official method, total of the two samples	Emerson method		
				I	II	Total
101*.........	Burnt lime	Pa.	37	15	15	30
102*.........	Burnt lime	Ohio	40	20	19	39
103*.........	Burnt lime	Va.	35	16	13	29
Average....	....	....	....	......	......	......
201..........	Hydrated lime	Texas	29	23	29	52
202..........	Hydrated lime	Fla.	45	34	21	55
203*.........	Hydrated lime	Va.	40	18	18	36
204*.........	Hydrated lime	Texas	40	22	19	41
205*.........	Hydrated lime	Pa.	38	20	15	35
206*.........	Hydrated lime	Ill.	36	19	15	34
207*.........	Hydrated lime	Va.	40	20	18	38
208*.........	Hydrated lime	Utah	40	17	18	35
209*.........	Hydrated lime	Wis.	45	15	14	29
210*.........	Hydrated lime	Mich.	32	15	14	29
Average....	....	....	....	......	......	......
301*.........	Air-slaked lime	Va.	40	15	18	33
302*.........	Air-slaked lime	Va.	45	10	15	25
303*.........	Air-slaked lime	Va.	35	15	18	33
Average....	....	....	....	......	......	......
401..........	Gr. limestone	Va.	40	21	20	41
402..........	Gr. limestone	Va.	45	13	11	24
403..........	Gr. limestone	Va.	33	16	11	27
404..........	Gr. limestone	Va.	25	12	16	28
405..........	Gr. limestone	Texas	30	12	11	23
406..........	Gr. limestone	Pa.	25	15	10	25
407†.........	Gr. limestone	Va.	30	12	12	24
408..........	Gr. limestone	Va.	32	15	20	35
409..........	Gr. limestone	Va.	33	15	13	28
410..........	Gr. limestone	Va.	40	15	12	27
411..........	Gr. limestone	Va.	35	18	17	35
412..........	Gr. limestone	Va.	36	22	26	48
Average....	....	....	....	......	......	......
501..........	Marl lime	Va.	37	17	19	36
502..........	Marl lime	Va.	38	20	18	38
503..........	Marl lime	Va.	35	20	22	42
Average....	....	....	....	......	......	......
601..........	Oyster shells	Va.	40	20	17	37
602†.........	Oyster shells	Va.	42	35	30	65
603..........	Oyster shells	Va.	38	22	20	42
604..........	Oyster shells.........	Texas	40	19	22	41
Average....	....	....	....	......	......	......
1001†........	Marble dust	Va.	45	40	30	70
1002..........	Aragonite	Ariz.	40	21	15	36
1003..........	Iceland spar calcite	Mont.	31	13	13	26
1004..........	Dolomite	N. Y.	36	15	21	36
1005..........	Dolomite	Mass.	32	18	15	33
1006..........	Magnesite	Wash.	42	20	32	52
1007..........	Plaster	Va.	45	32	22	54
Average....	....	....	....	......	......	......
Grand ave.	....	....	....	......	......	......

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*Samples for Emerson method weighed on hydrometer submerged in KCl solution and
‡Plus signs (+) indicate that one or two drops of acid were required in addition to that
but the coarse graduations on the reaction tube make it impossible to estimate this small
100% by an amount too small to read on the scale of the reaction tube.

Official and Emerson methods for analyzing agricultural liming materials.

CaCO$_3$ equivalent by						Difference between the two methods, % CaCO$_3$ equivalent
Official method, %			Emerson method, %			
I	II	Ave.	I	II	Ave.	
181.1	180.3	180.70	180.0	180.0	180.0	0.70
207.6	207.0	207.30	208.0	205.4	206.7	0.60
177.2	178.1	177.65	181.2	178.0	179.6	1.95
....	....	188.55	....	....	188.77	1.08
134.7	134.8	134.75	136.0	133.6	134.8	0.05
135.2	134.9	135.05	134.0	133.2	133.6	1.45
132.9	133.5	133.30	137.2	136.0	136.6	3.30
133.8	134.4	134.10	134.0	133.6	133.8	0.30
135.4	135.8	135.60	136.0	134.0	135.0	0.60
136.4	136.9	136.65	136.0	136.8	136.4	0.25
123.6	123.4	123.50	124.0	124.0	124.0	0.50
164.0	165.1	164.50	162.0	164.0	163.0	1.50
161.6	161.4	161.50	160.8	160.0	160.4	1.10
136.1	135.5	135.55	136.0	136.0	136.0	0.45
....	....	139.45	....	....	139.36	0.95
122.5	122.2	122.35	122.0	123.0	122.5	0.15
125.1	125.7	125.40	124.0	125.2	124.6	0.80
160.5	160.9	160.70	158.0	157.2	157.6	3.10
....	....	136.15	....	....	134.90	1.35
98.1	99.0	98.55	99.5	99.5	99.5	0.95
100.3	100.5	100.40	100+‡	100—	100.0	0.40
102.7	102.1	102.40	101.5	101.5	101.5	0.90
101.5	102.0	101.75	100.0	100.0	100.0	1.75
100.5	100.5	100.50	100+	100+	100+	0.50
102.1	102.2	102.15	100+	100+	100+	2.15
101.6	101.5	101.55	100+	100+	100+	1.55
99.3	99.0	99.15	98.0	99.0	98.5	0.65
101.4	101.1	101.25	100+	100+	100+	1.25
101.8	101.6	101.70	100+	100+	100+	1.70
100.0	99.8	99.90	99.0	99.0	99.0	0.90
82.4	82.3	82.35	83.0	83.0	83.0	0.65
....	....	99.30	....	....	98.45	1.11
94.6	94.1	94.35	93.0	95.0	94.0	0.35
98.7	98.9	98.80	98.0	98.0	98.0	0.80
96.3	96.8	96.55	96.0	97.0	96.5	0.05
....	....	96.56	....	....	96.17	0.40
114.5	114.2	114.35	116.0	114.0	115.0	0.65
64.6	64.7	64.65	68.0	67.0	67.5	2.85
95.4	95.3	95.35	96.0	96.0	96.0	0.65
100.0	100.2	100.10	100—	100.0	100.0	0.10
....	....	93.61	....	....	94.62	1.06
94.2	93.0	93.60	97.0	98.0	97.5	3.90
100.0	99.8	99.90	100+	100.0	100.0	0.10
100.0	100.6	100.30	100+	100—	100.0	0.30
108.7	108.6	108.65	108.0	107.0	107.5	1.15
108.9	108.8	108.85	108.0	108.0	108.0	0.85
57.9	57.5	57.7	56.0	54.0	55.0	2.70
20.1	20.0	20.05	22.0	20.0	21.0	0.95
....	....	84.15	....	....	84.14	1.42
....	....	119.68	....	....	119.48	1.06

equipped with special pan. †Samples dark colored; difficult to distinguish end point.
used by 100% CaCO$_3$-equivalent material; hence, the CaCO$_3$ equivalent is larger than 100%
amount accurately. Minus (—) signs indicate that the CaCO$_3$ equivalent was less than

not necessary, the Emerson method will usually be found to be more rapid than the official method when considered from the standpoint of the individual samples. Thus, it may be noted from Table 1 that the Emerson method required only about one-half as much time as the official method to complete a single determination. This advantage of the Emerson method may be of value to operators of commercial lime plants, either in regulatory work or in prospecting operations where only rough estimates are needed. However, where more than one determination is desired, or where a number of samples are to be tested, the official method largely overcomes its single-determination handicap, providing standardized reagents are available in the laboratory. The principal reason for this is that two determinations by the official method require very little more time than one determination. The second sample may be weighed while the first is being boiled and the first sample may be cooled and titrated while the second is being boiled. Hence, the additional time required by the second sample is limited to the duration of the cooling and titrating operations, which usually required from 5 to 8 minutes. The Emerson equipment does not permit of handling two samples concurrently; one analysis must be completed before the next is started. Hence, the Emerson method loses its single-determination advantage when more than one test is made.

DISCUSSION

Although many of the results obtained by the Emerson analyzer would be regarded as inaccurate by the analytical chemist, this equipment appears to be sufficiently accurate for routine determinations of the neutralizing value of liming materials. Table 1 shows that for approximately two-thirds of the total number of samples analyzed, the values obtained with the Emerson equipment agree to within 1% $CaCO_3$ equivalent with the values obtained by the official method. This is as much accuracy as is expected by most of the individuals who request analyses, and in some cases is more accuracy than is expected. Certainly, it is as much accuracy as is *necessary* in service and regulatory work. As to how much more deviation from the official values than 1% $CaCO_3$ equivalent may be tolerated will depend on the motives of the individuals seeking information and on the state regulations governing the sale of agricultural liming materials. Individuals who expect to make private use of lime deposits are usually interested in approximate values only. In such cases deviations of 2, 3, or even 5% $CaCO_3$ equivalent would be acceptable. However, individuals who wish to market liming materials usually desire to know and to use in advertising the highest values that can be sustained by analysis without making the vendor subject to the penalties of the law or laws regulating the commerce of liming materials. In Virginia the agricultural lime law allows deficiencies up to "ten per centum in value below the value of the manufacturer's guarantee" before penalty assessments may be enforced.[5]

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[5] Section 1137 of Chapter 49 of the Code of Virginia, as amended and re-enacted by acts of the General Assembly of the Commonwealth of Virginia. 1920.

The phrase "ten per centum in value" has reference to the monetary value of the material tested rather than to its acid neutralizing value. For materials which have a $CaCO_3$ equivalent of 100%, 10% of the monetary value is of course equivalent to 10% of the acid neutralizing value; but for materials which test more than 100% $CaCO_3$ equivalent, 10% of the monetary value is equivalent to more than 10% of the acid neutralizing value when the latter is expressed as percentage $CaCO_3$ equivalent. Thus, a freshly burnt lime, when tested by the Emerson equipment, may deviate approximately 18% $CaCO_3$ equivalent from the values obtained by the official method without being considered as 10% in error either in monetary value or in neutralizing value. On the other hand, for materials of less than 100% $CaCO_3$ equivalent, 10% of the monetary value is equal to less than 10% the neutralizing value ($CaCO_3$ equivalent). Thus, if a low-grade material tests 50% $CaCO_3$ equivalent, the values obtained by the Emerson method would have to agree to within 5% $CaCO_3$ equivalent with those of the official method in order to comply with the deficiency limit of 10% in (monetary) value. The largest overestimation obtained by the Emerson equipment in the studies reported here is 3.90% $CaCO_3$ equivalent, and it is therefore apparent that the values obtained by this equipment are well within the limit of deficiency allowable by law in Virginia until the acid neutralizing value falls below 40% $CaCO_3$ equivalent. And, since materials testing as low as 40% $CaCO_3$ equivalent are seldom used for liming purposes, it is necessary to conclude that the Emerson analyzer is satisfactory and dependable for testing liming materials in Virginia.

With its accuracy and dependability established, it seems desirable to call attention to the fact that the Emerson equipment has another feature of value in its portability. This feature should appeal to vendors of liming materials who do not have immediate access to an analytical laboratory, for it reduces to a minimum the necessity of sending samples to service agencies for analysis.

SUMMARY AND CONCLUSIONS

The study reported here was undertaken to determine (1) the applicability of the Emerson portable lime analyzer for estimating the neutralizing value of various liming materials and (2) to determine whether it is sufficiently accurate to be usable in Virginia under the provisions of the state agricultural lime law.

It was found that the equipment was not suitable for testing the fluffy limes, such as burnt, hydrated, and air-slaked, because the hydrometer pan supplied by the manufacturer is too small to receive the required amount of material in weighing out the sample for testing. Modifications have been suggested for making the equipment usable for testing the fluffy limes.

The Emerson analyzer, as sold by the manufacturer, was found to be well adapted to testing ground limestones, marls, and oyster shells.

The accuracy of the values obtained by the Emerson equipment was judged by their agreement with values obtained by the tentative method of determining the neutralizing value of liming materials as listed by the Association of Official Agricultural Chemists. The values obtained by the two methods differed by less than 1% $CaCO_3$ equivalent in 64% of the total number of samples tested, by less than 2% $CaCO_3$ equivalent in 86% of the tests, by less than 3% $CaCO_3$ equivalent in 93% of the tests, and by less than 4% $CaCO_3$ equivalent in all of the tests. Since a deficiency of 10% in value is allowable by the agricultural lime law in Virginia, it is concluded that the Emerson analyzer is well within the limit of accuracy required for testing liming materials in this state.

The Emerson method is usually more rapid than the official method when single determinations only are made. When duplicate determinations are made, the two methods require approximately the same length of time.

Materials which have a $CaCO_3$ equivalent of more than 100% may be tested in slightly less time with the Emerson equipment than by the official method. However, materials which have a $CaCO_3$ equivalent of less than 100% may be tested more quickly by the official method.

NOTES

HEIGHT OF CUTTING SWEET CLOVER AND INFLUENCE OF SWEET CLOVER ON SUCCEEDING OAT YIELDS[1]

In preparation for a pasture experiment, later moved to a larger and more accessible piece of land, five pasture mixtures were each seeded to duplicate 1-acre areas. In the seeded field an acre of white sweet clover lay between one of an alsike clover and grass mixture and one of a white clover and bluegrass mixture. When the experiment was moved the field was left ungrazed. The yields of sweet clover hay were obtained by cutting 16 1-meter plats in each acre, the sweet clover being subsequently mowed in three parts with stubble 4, 8, and 12 inches tall, respectively. There were nine 10 x 10 foot plats in each acre for a check. The yields for the 2 acres of sweet clover were 2.53 ± .069 and 2.81 ± .026 tons of air-cured hay, respectively. Later in the season notes were taken for the three heights of cutting, as shown in Table 1.

TABLE 1.—*Effect on the growth of the second crop of cutting white sweet clover 4, 8, and 12 inches high.*

North acre			South acre		
No. plats	Treatment	Second growth	No. plats	Treatment	Second growth
3	Cut 4 in.	None	3	Cut 4 in.	None
3	Cut 8 in.	Few shoots; 2 or 3 in. long; 10% crop	3	Cut 8 in.	None
3	Cut 12 in.	Full crop; 12 in. high	3	Cut 12 in.	Full crop; 15 in. high

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[1] Help from R. W. Woodward in harvesting the crop and from A. F. Bracken for analysis of oat grain is acknowledged.

Next season the field was plowed and seeded to oats. A visibly greater yield was noted on the sweet clover land. Yields were taken by means of 9 square meters on each acre—one acre previously growing sweet clover and one on each side sown to pasture mixtures already noted. The grain was analyzed and the protein in the grain determined. The acre yields and the nitrogen yields to the acre are shown in Table 2.

TABLE 2.—*Acre yield of oat grain and protein in the oat grain on land previously cropped to three different pasture mixtures.*

Previous treatment	Acre yield of oat grain, bu.	Protein in grain, lbs. per acre	Straw, lbs. per acre
White clover and bluegrass....	71.5±5.1	196.9	1,765
White sweet clover...........	108.1±4.2	336.9	3,246
Alsike clover and grasses......	85.5±5.0	235.5	Data lost

From appearances, there is little doubt of higher protein content in the straw grown on the sweet clover land, but because of a misunderstanding the straw was not alanyzed.—GEORGE STEWART, *formerly Agronomist, Utah Agricultural Experiment Station; now Ecologist, U. S. Forest Service, Ogden, Utah.*

MISCELLANEOUS GENETIC DATA FROM WHEAT CROSSES[1]

During 1931 and the 2 or 3 years immediately preceding, genetic data were taken on six wheat crosses made primarily to secure superior strains for economic production. These somewhat fragmentary data were to have been added to, but due to a change in the writer's position this was not accomplished and they are here presented with the hope that they may be of value. In all cases a single spike of the male parent furnished pollen for a single spike of the female parent and a single F_1 plant furnished all the kernels used in propagating the F_2 plants. The grain from each F_2 plant seeded a 30- to 50-plant F_3 progeny row, and all genetic data were taken by obtaining the genetic composition of the F_2 plant from the breeding behavior of the F_3 offspring of that plant.

1. *Hard Federation x* $\frac{\textit{Sevier}}{\textit{Dicklow}}$ (F_{22}).—A pure-breeding awned and compact-spiked hybrid offspring of Sevier x Dicklow (F_{22}), promising in yield but weak-strawed, was crossed with awnless and lax-spiked Hard Federation. Of 284 F_3 progeny rows, 67 bred true for dense spikes and 72 for lax spikes, while 145 segregated. On a 1:2:1 segregation, $P = .88$.

2. $\frac{\textit{Sevier}}{\textit{Dicklow}}$ *(G-149) x Hard Federation.*—Strain G-149 was a pure-breeding, high-yielding, awned, white-chaffed, rust-resistant segregate from a cross of Sevier x Dicklow. Being weak-strawed, it was crossed

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[1] Acknowledgment is made of help received from D. C. Tingey and R. W. Woodward in growing the crop and taking the data.

with Hard Federation in the hope of adding the superior standing ability of the awnless red-chaffed Hard Federation. Chaff color segregated 63:102:47 for homozygous bronze, heterozygous, and homozygous white. This gave a P of .29 on the basis of a 1 : 2 : 1 segregation. The segregation for awns gave nine breeding classes, as called for on a two-factor basis, in the ratio of 1:2:2:4:1:2:1:2:1. True-breeding progenies were obtained for fully awned, for awnless, and for two distinct partly awned spikes. P = .30.

3. *Hybrid 128 x Sevier.*—The stiff-strawed, awn-tipped, winter-hardy Washington Hybrid 128 was crossed with the fully awned non-hardy but high-yielding Sevier. Data taken on awns gave in 250 F_3 progenies 63 homozygous awn-tipped progenies; 62 homozygous fully awned; and 125 segregating. On a 1:2:1 basis x^2 is almost 0, P therefore being extremely high.

4. *Ridit x Sevier 59.*—The smut-resistant, awn-tipped, lax-spiked, winter-hardy Ridit was crossed with the smut-susceptible, awned, intermediate-spiked Sevier. Data were taken regarding segregation for awn behavior and spike density. There were 97 progenies. In both awn behavior and spike density, 1:2:1 ratios were obtained. Progenies homozygous for awn tips, segregating, and homozygous for full awns were obtained in the proportion of 25, 48, and 24, respectively. X^2 for awns was less than 1, therefore, P was extremely high. For spike density, there were 20, 57, and 20 homozygous compact-spiked, segregating, and homozygous lax-spiked homozygous progenies. P = .23. The homozygous, compact-spiked progenies had really compact spikes; distinctly more so than the more compact parent, Sevier.

5. *Turkey x Federation.*—Turkey, the standard winter wheat of the region, was crossed on Federation in an effort to improve the standing ability. Data on awns and chaff color were taken on the 354 F_3 progenies. There were nine classes of awns, four of which were true-breeding, as follows: (1) Fully awned, (2) awnless, and (3) and (4) two distinct partly awned types. On the basis of 1:2:2:4:1:2:1:2:1 segregation, P = .85. There were, therefore, two distinct factors for awns, similar in a general way to the two involved in previously reported Sevier x Federation crosses. Chaff color for bronze and white segregated 1:2:1, giving a P of .37. Dwarfs were obtained and separately reported. Three factors for grain color were observed, but since completing the ratios required additional generations and since this had been carefully worked out in another cross, it was not done with this cross.

6. *Ridit x Turkey 989.*—A high-yielding selection of fully awned Turkey wheat was crossed on awn-tipped Ridit for its smut-resisting qualities. Awn data showed 75 F_3 progenies to be true-breeding, awn-tipped forms and 61 for fully awned forms, with 114 segregating. On a 1:2:1 basis, P = .18.—GEORGE STEWART, *formerly Agronomist, Utah Agricultural Experiment Station; now Ecologist, U. S. Forest Service, Ogden, Utah.*

THE PRACTICAL APPLICATION OF IAROVIZATION

Iarovization (vernalization) is a seed treatment consisting of a slow and limited germination at low or high temperatures, depending on the crop, that at high temperatures being restricted by deficient moisture and by salt solutions. According to published claims, by means of a low temperature treatment winter wheat may be seeded successfully in the spring and the growing period of spring wheat and other crops may be shortened materially. It has been reported to be widely applied in Russia.

Low temperature treatment of winter wheat to permit spring seeding is not new, as it was well known and occasionally practiced in this country 75 to 100 years ago. Modern research on iarovization seems to have been based largely upon results reported by Gassner in Germany in 1918.

No direct evidence regarding the practical value of low temperature iarovization of winter wheat in the United States is available. In 62 field experiments in seven states, winter wheat coming up in the spring after having been "naturally iarovized" by late fall or winter seeding yielded an average of 1.5 bushels per acre less than spring wheat and 8.4 bushels less than early fall sown winter wheat.

Iarovized sorghum seed (treated at high temperatures as recommended for crops of this type) failed to produce earlier maturity or better growth than untreated seed of the same 41 varieties in experiments conducted in 1933. The germination of the seed of most of the varieties was either greatly reduced or entirely destroyed by the treatment. Other spring grains showed little or no effect of iarovization except in reduced germination.

No satisfactory method of iarovizing seed under farm conditions has yet been devised. The obvious difficulties of temperature control, such as excessive sprouting, moldy seed, low germination, and drying the seed, or seeding moist, partly germinated seed, are ample evidence that iarovization is not of immediate value to the practical farmer.

A mimeographed circular prepared by the writer describing some early trials and practical limitations of iarovization has recently been issued.—JOHN H. MARTIN, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.*

THE RELATION OF THE CARBON-NITROGEN RATIO OF A MULCH TO THE ACCUMULATION OF NITRATES IN SOIL[1]

In a previous paper,[2] evidence of pronounced accumulation of nitrates under a mulch of waste hay and straw was reported. In a second paper,[3] it was shown that nitrates did not accumulate under this mulch in quantities sufficient to appear with some degree of regularity until after 3 years. In this paper it was suggested that nitrification occurred mainly in the lower layers of the mulch rather than in the soil and only after the carbon-nitrogen ratio of the mulch had been considerably narrowed through processes of decay.

In Table 1 are given analytical data in support of the latter hypothesis. The "fresh mulch" sample was taken in the spring of 1932 from the newly applied material. The other samples were taken in the fall of 1931 from the mulch which had accumulated from 1928 to 1931 at different levels, as indicated below.

TABLE 1.—*Percentage of carbon and nitrogen in mulch material.*

Sample	Total C %	Total N %	C/N ratio
Fresh mulch..........	44.96	1.20	37.5 : 1
Top of mulch.........	43.61	1.72	25.4 : 1
Middle of mulch......	37.29	2.50	14.9 : 1
Bottom of mulch......	24.39	1.72	14.2 : 1

Carbon was determined by the dry combustion method; total nitrogen by the Kjeldahl-Gunning method.

Due to the intimate contact of the mulch and the soil, it is probable that the lowest sample was contaminated to a minor extent with soil. The sand storms to which this valley is subject undoubtedly contaminated all three layers to a slight degree.

These data and those of the previous papers indicate that under the conditions of this experiment a period of about 3 years is necessary to reduce the carbon-nitrogen ratio of the mulch to the point where nitrates are produced in excess of the needs of the decay organisms. The upper limit of this ratio appears to be about 15:1.—W. J. Moore, Jr., and A. B. Beaumont, *Massachusetts Agricultural Experiment Station, Amherst, Mass.*

A SIMPLE METHOD FOR MAKING SOYBEAN HYBRIDS

Artificial crossing in soybeans is at best a difficult and tedious operation and is not infrequently attended by negative results. In an effort to overcome these difficulties and still utilize hybridization as an effective means in improving soybeans, the writer employed a method in 1930 that has proved very gratifying. Since no such method has come to his attention, it is described here so that others may test its efficiency and suitability.

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[1] Contribution No. 185 of the Massachusetts Agricultural Experiment Station, Amherst, Mass.

[2] BEAUMONT, A. B., SESSIONS, A. C., and KELLY, O. W. Nitrate accumulation under a mulch. Soil Science, 24: 177–185. 1927.

[3] BEAUMONT, A. B., and CROOKS, G. CHAPMAN. The influence of a mulch on soil nitrates. Soil Science, 36: 121–123. 1933.

After choosing the two parents to be crossed, the seeds of each were sown alternately 3 to 4 inches apart in rod rows in the field. The rows were 30 inches apart, although they might to advantage be seeded closer together. Twenty rod rows were planted from each pair of parents. Six such blocks representing six crosses were thus planted.

Just prior to the blossoming period each block representing one pair of parents was surrounded with a cheesecloth fence 36 inches in height. This served as a partial barrier to the transfer of pollen by wind and insects from block to block, although the insects had free access over the top. In order to make as much use as possible of the honeybee, the breeding nursery was placed within 200 feet of 15 honeybee colonies. Whether it was the scarcity of nectar on other plants due to the hot, dry summer or to the close proximity of the soybean nursery, or both, was not decided, but repeated observations showed clearly that the honeybee was a very frequent visitor to the soybean breeding nursery.

Some estimate of the success of this so-called bulk method of crossing can be formed from an examination of the data in Table 1. The data represent crosses between brown and gray pubescent parents so that by planting seed from the recessive gray pubescent plants, the amount of natural crossing is readily calculated.

TABLE 1.—*The relative number of hybrid seeds owing to natural crossing in certain varieties and strains of soybeans.*

Cross No.	Parent strains (plants grown alternately, 1930)	Total number of seeds from phenotypically gray plants sown in 1931	No. of brown plants in F_1, 1931*	Percentage of brown plants
2.....	Dunfield No. 28 and Midwest	89,980	71	0.79
3.....	Illini and Manchu No. 35	6,406 (selected)	89	1.39
3a....	Illini and Manchu No. 35	2,058 (rejected)	50	2.43
4.....	Illini and Midwest	9,325	35	0.38
5.....	Midwest and Dunfield No. 70	7,846	36	0.46
7.....	Dunfield No. 70 and Manchu No. 31	4,500	51	1.13

*Number of plants that proved to be hybrids as determined by the progeny test in 1932. A sixth cross was made with even apparently greater success, but the progeny test was not applied so that the data are not reported.

The method followed was to harvest all gray plants; then number and thresh each separately. The seed from each was then examined and that from plants which had produced seed that was normally developed (plump and properly matured) was chosen for planting. Each of the crosses, except No. 3, was handled in this way. In the case of No. 3, after the plants with normal seed were selected, the balance or the rejected plants were bulked. From this bulk a random sample of 2,058 seeds was planted. The first lot was designated No. 3 and the latter No. 3a. Just how much the selection of plants bearing normally developed seed has influenced the end results is uncertain. In this instance, however, it will be noted that the results were considerably better from the rejected than from the selected plants.

The data indicate that the percentage of natural hybrids as based on gray pubescent plants varied from 0.38 to 2.43. If it is assumed that the reciprocal natural cross is as likely to occur as the ones here described, the percentage of natural crossing which lead to new hybrids under these conditions would range from 0.76 to nearly 5. It will be observed that in all cases the lower percentages occurred when the Midwest variety was used as one parent. This may be explained by the fact that, other things being equal, this variety usually blossoms later than any of the others used in these tests.

It will be noted that the amount of natural crossing is much higher than has been reported by previous writers. The method proved so successful in producing hybrid seed in this single attempt that the test has not been repeated. So many natural hybrids were produced that it has scarcely been possible to cope with the great volume of recombinations made available. The fact that the results are so consistently good among the several strains and varieties used, however, seems to justify the conclusion that where one merely desired to produce hybrids the method warrants a trial. It would probably not lend itself to plant genetic studies since the identity of the pollen parent is lost.—G. H. Cutler, *Purdue University Agricultural Experiment Station, Lafayette, Indiana.*

BOOK REVIEWS

RECENT ADVANCES IN THE STUDY OF PLANT VIRUSES

By Kenneth M. Smith and F. T. Brooks. Philadelphia: P. Blakiston's Son & Co., Inc. XII+423 pages, illus. 1934. $4.

In recent years one of the most active branches of plant pathology has been the study of the virus diseases of plants. An enormous literature has accumulated on this subject. Much of it is difficult of access. No comprehensive review of these investigations has appeared. This book, therefore, brings together this material and presents a critical survey of this group of plant diseases. It will serve as a reference until the progress and correlation of knowledge allow a more comprehensive treatise to be written.

A list of the subject material in each chapter will serve to indicate the contents as well as the completeness of the presentation. Chapter I contains a definition of the viruses and some theories as to their nature. Chapters II, III, and IV refer to symptomatology and physical properties. Chapters V, VI, and VII refer to insects in relation to viruses. Chapter VIII deals with the transmission and spread of plant viruses, and Chapter IX presents the physiology of virus diseases in plants. Chapters X and XI suggest some aspects of the further study of plant viruses, while Chapter XII deals rather specifically with potato virus diseases. Chapters XIII and XIV give a descriptive account of the virus diseases of plants, other than the potato, classified according to their hosts.

Following each subject division citations on the subject matter are given. In all, 866 entries are listed, although some citations have been used more than once. A glossary of terms used in virus studies and an index of authors, as well as a general index, are given. The book crystallizes the present knowledge of virus diseases and for this reason will be a fertile stimulus to further investigation of this intriguing group of plant diseases. (J. K. W.)

HANDBOOK OF SOIL SCIENCE: VI. PHYSICAL PROPERTIES OF SOILS

E. Blanck, Editor. Berlin: J. Springer. 423 pages, illus. 1930. RM 43.6 unbound; RM 46.6 bound.

A great philosopher has once said that in every science there is only so much science, properly so-called, as there is mathematics. If this were taken as a criterion, soil science indeed would be very "scientific" as judged by this book on physical properties of soils.

Though many agronomists are not particularly mathematically inclined, they will nevertheless gain immensely by reading the text alone, simply skipping the equations. One is impressed how much experimental work and thinking in soil physics has been done, particularly by engineers and physicists. I. Zunker's elaborate treatise on the "Soil Water System" (154 pages) and T. Schubert's valuable chapter on "Soil and Heat," including soil temperature, are typical examples. They are full of interesting and important facts, often unknown to soil scientists. The other equally well written chapters are "Mechanical Composition of the Soil," by A. Demsch; "Evaporation of Water from the Soil," by M. Helbig; "The Soil-air-system," by F. Giesecke; and "Soil and Electricity and Radio-activity," by V. F. Hess.

No agronomist interested in soil physics can afford to overlook this valuable volume. (H. J.)

CALCULATION AND INTERPRETATION OF ANALYSIS OF VARIANCE AND COVARIANCE

By George W. Snedecor. Ames, Iowa: Collegiate Press, Inc. 105 pages. 1934. $1.

A new statistical method is of little practical use to the great body of experimenters unless they understand its various applications. Fisher's analysis of variance has a wide use in the study of experimental design as well as in the interpretation of data, but it introduces a number of new concepts and methods that are more or less confusing to workers with limited mathematical training. Even to some who have had considerable grounding in the ordinary statistical mathematics, the numerous practical applications of the method are not readily apparent.

This small volume by Dr. Snedecor will be welcomed by research workers because it aims to present systematically the chief forms of analysis of variance and covariance now in use. Ten different types are presented with the detailed calculation and explanation of the meaning of each, progressing from the simple through the more intricate forms. The data are taken from a wide range of research and new terms and concepts are carefully explained.

The book is concise without omitting essentials and is clearly written. One cannot read it without feeling that it supplies a pressing need for an authoritative presentation of this difficult subject, and that at the same time it gives a wider view of the application of this type of analysis to research problems than has appeared to the majority who should find use for these methods. (F. Z. H.)

CHARLES DARWIN'S DIARY OF THE VOYAGE OF H.M.S. "BEAGLE"

Edited from the MS by Nora Barlow. New York: The Macmillan Company. XXX + 451 pages, illus. 1933. $6.50.

To any who have read and reread that greatest of travel books by Charles Darwin, *Journal of Researches into the Natural History and Geology of the Countries Visited during the Voyage of H. M. S. Beagle Round the World, Under the Command of Capt. Fitz Roy, R. N.*, the publication of the diary of the voyage is an interesting and worthwhile addition. On the expeditions and side trips which he made during this voyage, Darwin carried small pocket notebooks in which he kept rough notes of his experiences. These notebooks totaled 18 in number, and from them he wrote a more elaborate diary of his voyage. From this diary, in turn, he later wrote the *Journal*, the first edition of which was published in 1839 and the second in 1845. In this rewriting of the diary approximately one-third of the manuscript was omitted and the other two-thirds condensed. At the same time the total number of words increased from 189,000 in the manuscript to 224,000 in the first edition, due to the author's elaborations and discussions.

There is, then, a scientific value in those portions of the diary which are published here for the first time. Yet quite aside from the scientific aspects, the reader is impressed by the glimpse into the developing life of one of the world's greatest scientists. To most people Charles Darwin is seen as an elderly mature individual of advanced thinking. In this book, the reader feels the live and fresh youth of the young scientist in his formative years. He was 22 years of age when he embarked upon the *Beagle*.

His points of view on various subjects change during the voyage. For example, he becomes increasingly impressed by the record of geology until by the end of the diary he seems especially fascinated by it, enumerating in detail the geological features that he encounters. Furthermore, at Valpariso in 1834, he says, "It seems not a very improbable conjecture that the want of animals may be owing to none having been created since this country was raised from the sea." The species puzzle in the Galapogos Islands presented a different problem from which his theory of the origin of species evolved.

His intense interest in the tropics is apparent by his vivid descriptions and the constant reference he makes to its beauty and to the power it holds over him. Moreover, Humboldt's *Geography* seems to have been a constant companion and a never ceasing source of inspiration and help. The hardships of the voyage and the difficulties he encounters serve to emphasize at what cost Charles Darwin acquired his information.

The volume is well printed, the material being presented chronologically day by day covering the period from 1831 to 1836. At the beginning are some helpful notes on the personnel of the expedition as well as diagrams of the *Beagle* and its accommodations. At the back of the book are eight pages of elaborating notes, together with two maps covering the voyage. (H. B. T.)

AGRONOMIC AFFAIRS

NEWS ITEMS

DR. H. K. HAYES, Chief of the Department of Agronomy and Plant Genetics of the University of Minnesota, gave the fifth of the series of annual lectures under the Frank Azor Spragg Memorial Fund, at Michigan State College, January 23 to 26. The subjects dealt with by Dr. Hayes were as follows: The Rôle of Plant Breeding in Crop Improvement; Some Biometrical Methods in Crops Research; The Multiple Factor Hypothesis and its Meaning to the Plant Breeder; Modern Methods of Corn Breeding; and The Control of Pathogenic Diseases by Breeding.

D. C. SMITH, Assistant in the Division of Agronomy and Plant Genetics, University of Minnesota, has been appointed Assistant Agronomist at Oregon State College. Mr. Smith takes the place of Dr. E. N. Bressman who recently resigned to accept a position in the U. S. Dept. of Agriculture.

DR. CHARLES E. KELLOGG of the North Dakota Agricultural College was promoted from Assistant Professor of Soils to Professor of Soils, effective January 1, 1934. Dr. Kellogg has been granted a short leave of absence, beginning February 1, to assist the U. S. Bureau of Chemistry and Soils with some special work in connection with the Soil Survey.

M. H. CUBBON, formerly Assistant Professor of Agronomy, Massachusetts State College, has accepted a position with the Farm Credit Association and has entered upon his new duties in Washington, D. C.

DR. H. H. LOVE, who is on leave of absence from Cornell University to serve as Agricultural Adviser to the Ministry of Industries of the Chinese Government, writes that he has just concluded his third Winter Training Institute on Crop Improvement held in connection with the National Agricultural Research Bureau. These Winter Training Institutes constitute an important part of Dr. Love's work in China, namely, that of the training of men. This is the largest Winter Institute in the point of attendance and courses that has been held. There were 90 delegates from 12 provinces in addition to 19 local men. The courses offered covered all phases of work fundamental to crop improvement and included a thorough discussion of all the latest methods for experimental plat lay-out and the analysis of the results. These Winter Training Institutes are very useful as Dr. Love has already been able to see improved technic at different experiment station centers since the training was begun during the first Institute 2 years ago.

A. L. GRIZZARD, for the past five years on the staff of the Michigan State College, has resigned his position as Research Assistant to accept the position as Assistant Professor of Soils in the Department of Agronomy at the Virginia Polytechnic Institute. Professor Grizzard will be in charge of field experiments in soil fertility in western Virginia.

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VARIETAL COMPETITION AS A FACTOR IN YIELD TRIALS WITH SUGAR BEETS[1]

F. R. IMMER[2]

It has been demonstrated by various workers that competition effects between adjacent rows of different varieties of cereals or other crop plants, in cases where the varieties used differ in growth habit, may introduce a serious error in conducting yield trials. Only a meager amount of information is available on the effect of competition between adjacent rows of different varieties of sugar beets. It is certain that in many instances the possibility of the existence of such competition effects between varieties has been ignored in planning and harvesting sugar beet variety trials. To determine the effects of such competition a test was designed and conducted at the South East Experiment Station of the University of Minnesota in 1930, 1931,[3] and 1932, wherein two standard brands of sugar beets differing in growth habits were used. These brands were grown alternately in one-row plats to determine whether the differences were of such magnitude as to affect yields seriously. As a standard for comparison, four-row plats of the same brands were grown in alternation, from which at time of harvest each outer row was removed and the two central rows were harvested. This plan was suggested by Kiesselbach[4] and was the plan used by him in demonstrating the importance of competition between different varieties of small grains or corn when grown alternately in single-row plats.

Seed of the commercial brands, Old Type and Extreme Pioneer, was used. The Old Type brand is designated by the commercial seed company[5] producing it as high in tonnage yield and moderate in sucrose percentage, whereas the Extreme Pioneer is designated as considerably lower in tonnage yield but higher in sucrose content than the other brand. The seed was planted at the rate of 25 pounds of seed per acre in rows 22 inches apart in 1930 and 1931 and in rows 20 inches apart in 1932. At time of thinning the beets were blocked and thinned to a single beet per 12 inches of row. At harvest, the beets next to obvious skips in the row were removed, and only beets normally competitive were harvested. Yields were expressed in terms of a 100% stand of normally competitive beets.

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[1] A cooperative study between the Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, and the Minnesota Agricultural Experiment Station. University Farm, St. Paul, Minn. Received for publication, April 26, 1933.

[2] Associate Geneticist.

[3] Credit is due to S. M. Raleigh, Agent, Div. Sugar Plant Investigations, for field and laboratory assistance in 1931.

[4] KIESSELBACH, T. A. Studies concerning the elimination of experimental error in comparative crop tests. Nebr. Agr. Exp. Res. Bul. 13. 1918.

[5] Kleinwanzleben, Zuckerfabrik. Kleinwanzleben, Germany.

The determinations of the percentage of sucrose were made by the Sachs Le Docte cold-water-digestion method. In the single-row plats, one 10-beet sample was taken in 1930, two 15-beet samples in 1931, and one 20-beet sample in 1932. In the four-row plats, two 10-beet samples were taken in 1930, three 20-beet samples in 1931, and two 20-beet samples in 1932.

The coefficient of apparent purity in the 1930 and 1931 tests was obtained by multiplying the percentage of sucrose in the juice by 100, and then dividing this result by the Brix reading (correction for temperature being made).

In the 1932 tests the refractometer reading (corrected for temperature) was substituted for the Brix reading. The pounds of gross sugar per acre was computed by multiplying the yield of beets per acre (in pounds) by the sucrose percentage.

The two comparisons were made in two separate trials which were placed adjacent to each other in the same field. The two brands used in the one-row and four-row plats were replicated 10 times. In the case of the single-row series each brand was subjected to the competition of the other brand on two sides. In the four-row plat series only the central rows were harvested in order to reduce border row effect.

The errors were calculated for each year and for the average of the 3 years and are expressed in terms of standard errors of the mean. The results of the test are given in Table 1.

When grown in single-row plats the Old Type brand yielded 3.78 ± .44 tons more than Extreme Pioneer. In four-row plats, with the central two rows alone being harvested, the increase of Old Type over Extreme Pioneer was only 1.78 ± .31 tons. The difference between these two differences is 2.00 ± .54 tons. This difference is undoubtedly significant and demonstrates clearly that Old Type, the higher yielding sort, profited at the expense of Extreme Pioneer when these two brands were grown side by side in single-row plats.

While the unequal competition effects are definitely demonstrated as far as yield of beets is concerned, similar effects were not found for sucrose percentage or for the coefficients of apparent purity. The differences between Old Type and Extreme Pioneer in the single-row as contrasted with the four-row plats were 0.05 ± .14 and — 0.48 ± .69%, respectively, and these are not statistically significant. Old Type produced 834 ± 37 pounds more gross sugar per acre than Extreme Pioneer when grown in alternate single-row plats. When grown in four-row plats the difference was but 239 ± 85 pounds. The difference between these two differences is 595 ± 161, which is clearly significant. It should be noted, however, that the tonnage yield of beets was largely, if not entirely, responsible for this significant difference.

TABLE 1.—*Results obtained with two commercial brands, Old Type and Extreme Pioneer, grown in alternating single-row plats, compared with results from four-row plats in which only the center two rows were harvested, data given as averages of 10 replications in each case.*

Year	One-row plats		Four-row plats (central two rows harvested)	
	Old Type	Extreme Pioneer	Old Type	Extreme Pioneer
	Average Yield, Tons per Acre			
1930.....	16.97±.76	13.00±.76	16.39±.37	14.60±.37
1931.....	20.42±.36	15.38±.36	18.89±.50	16.48±.50
1932.....	16.13±.43	13.80±.43	14.77±.18	13.62±.18
Ave.....	17.84±.31	14.06±.31	16.68±.22	14.90±.22
Ave. dif..	3.78±.44		1.78±.31	
	Average Percentage of Sucrose			
1930.....	15.02±.21	15.80±.21	14.41±.13	15.48±.13
1931.....	13.34±.09	14.74±.09	13.43±.09	14.59±.09
1932.....	16.18±.05	16.55±.05	16.24±.09	16.71±.09
Ave......	14.85±.08	15.70±.08	14.69±.06	15.59±.06
Ave. dif..	—.85±.11		—.90±.08	
	Average Apparent Purity			
1930.....	85.43±.76	85.46±.76	84.66±.78	83.94±.78
1931.....	85.76±.88	86.21±.88	85.06±.26	85.29±.26
1932.....	85.68±.16	85.36±.16	86.12±.32	85.36±.32
Ave.....	85.62±.39	85.68±.39	85.28±.29	84.86±.29
Ave. dif..	—.06±.55		.42±.41	
	Average Pounds of Gross Sugar per Acre			
1930.....	5051±240	4113±240	4720±117	4512±117
1931.....	5444± 96	4527± 96	5069±115	4805±115
1932.....	5213±134	4567±134	4795± 71	4550± 71
Ave.....	5236± 97	4402± 97	4861± 60	4622± 60
Ave. dif..	834±137		239±85	

From the results obtained it is evident that in variety trials with sugar beets involving varieties or brands differing markedly in size of plants, that plats at least three rows wide must be used and at least one border row on each side of the plat must be discarded at harvest.

MATURITY OF SEED CORN IN RELATION TO YIELDING ABILITY AND DISEASE INFECTION[1]

BENJ. KOEHLER, G. H. DUNGAN, and W. L. BURLISON[2]

There has been considerable uncertainty with regard to when seed corn should be harvested in order to give the best performance when planted. Some farmers regularly select their seed from the crib from corn harvested sometime during the late fall or early winter. Some always select their seed in the field before the regular harvest and before there is much danger from frost, while others select their seed corn early only in seasons when they feel that the corn is in a condition in which it might be especially liable to injury by cold temperatures. This experiment was undertaken to see if there is any particular time for selecting seed which had best be adhered to regularly, and to see what effect harvesting at different stages of development has upon the seed with respect to its subsequent field performance.

MATERIALS AND METHODS

A strain of Reid Yellow Dent grown and selected many years at the University of Illinois was used thruout the 7 years of the experiment. It is an open-pollinated, full-season variety of the utility type. Planted at Urbana in the first half of May of a normal season, the ears were mature and the husks had turned brown by the middle of October, but most of the leaves of healthy plants were still green at that time. The average date for killing frost at this location is about October 18. Being open pollinated, and therefore, of diverse genetic constitution, some plants, of course, are killed sooner than others.

Each year the ears were selected at the different times from plant populations grown from mature, nearly disease-free seed on dark-colored grass land soils as found on the Station farm at Urbana. One hundred ears of each kind were selected each year. They were well protected by the husks and supported by sound shanks on plants visibly free from serious diseases as recommended in another publication (8).[3] On the day each selection was made, not all ears had developed to the same degree and selection was exercised to secure ears of fairly uniform development or maturity.

There is no standard terminology expressing definitely the degree of development in maturing seed. For the purpose in hand the terms below were arbitrarily chosen, but for comparison with the work of others such data as moisture in grain at harvest, dry weight of kernels, and number of days after fertilization (Table 1) will serve better. The stages of harvest are described below.

Milk stage.—This stage was selected at about 20 days after fertilization as judged by the emergence of silks. The grain moisture

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[1] Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Received for publication, May 8, 1933.

[2] Associate Chief in Crop Pathology, Associate Chief in Crop Production, and Head of Department, respectively.

[3] Numbers in parenthesis refer to "Literature Cited," p. 274.

TABLE 1.—*Vitality and certain physical characters of yellow dent seed corn harvested in different stages of maturity, 7-year average, 1924–1930, Urbana, Ill.*

Stage of maturity of seed	Average harvesting date	Approximate time since fertilization, days	Moisture content of grain when harvested, %	Weight per kernel at 12% moisture, grams	Test weight per bushel, lbs.	Specific gravity of grain	Vitality in germinator	
							Germination %	Kernels germinating strong, %
Milk.......	Aug. 19	20	74.3	0.104	43.3	1.11	89.9	7.7
Late milk	Aug. 27	28	58.8	0.177	49.2	1.19	96.3	25.7
Dent......	Sept. 6	38	43.6	0.280	56.9	1.26	98.7	77.9
Mature....	Oct. 13	75	28.6	0.350	57.8	1.28	98.9	76.7
Husking...	Nov. 30	123	22.1	0.348	57.9	1.27	90.4	62.3

content averaged 74.3% (Table 1). At this time the kernels had a high gloss and a pale cream color, the yellow pigment as yet being practically absent.

Late milk stage.—This selection was made 8 days later and at this time the moisture content averaged 58.8%. The gloss was not quite so high and some yellow pigment had developed, but the yellow color was much less developed than in the dent stage. The milky region that remained was just as fluid as in the earlier stage but not so extensive. The firmer portion of a somewhat cheesy consistency which was already present in the milk stage had increased in proportion. As it is a matter of relative extent of two very different regions separated by a narrow transition area (9), the term "dough" has not been used in this article.

Dent stage.—The dent stage was selected 10 days later when at least 90% of the kernels had dented, but the kernels had not developed very far beyond the initial denting as evidenced by their hardness when tested with the thumb nail. The average moisture content was 43.6%.

Mature stage.—At this time the ears were rather hard with 28.6% moisture in the kernels. The husks had turned straw color, but the stalks and most of the leaf surface were in most years still green. The kernels were well filled to the tips where they are attached to the cob (8, Fig. 14). The term "mature" seems to be indefinite as well as the other terms used above. Possibly it should not apply until the whole plant is very nearly dead from old age. At just what stage in the life of a corn plant the ear stops growth, when the environment is favorable for growth, does not seem to be known. In central Illinois, however, full-season varieties usually are killed by cold temperatures before they die of old age and ears as selected under this heading in this experiment are usually spoken of as being mature.

Husking stage.—In this case the ears were left on the standing stalks until late in November. This was not an additional stage of development, but simply an exposure to outdoor weather. The time selected was arbitrary. Husking time in central Illinois may be any time from late in October until late in February. The average moisture content was 22.1%.

As soon as harvested, the husks were removed and the ears were laid in Martin wire hangers in a well-ventilated room and an electric fan directed at them. When the earlier stages were harvested, the temperature was naturally warm; later steam heat was used to keep the room at a comfortable temperature. In mid-winter a 10-kernel germination test was made of each ear and only those ears which showed 100% germination were used for seed purposes. In addition, the original number of ears was reduced to one-half by selecting that half which showed best vigor and freedom from disease.

The field plat technic for yield tests was to grow eight replicates of each item in paired rows 20 hills long, three kernels per hill, check rowed. After it was observed that some of the seed selections produced poor stands, a border row was placed on each side of each replication which was not used in the yield test in order to eliminate possible border effects. Plantings were made near the middle of May when the soil temperature was high enough to give weak seed a fair chance. At this time the soil temperature at planting depth averaged approximately 61° F. With high-grade seed, however, plantings made May 1 to 10 have been found on the average to give highest yields under otherwise similar conditions.

In order to evaluate the significance of differences found in yield, odds of probability were calculated by Student's method.

LABORATORY GERMINATION

In mid-winter all the ears in the experiment each year were germinated simultaneously in a room-type germinator (8, page 132) at a temperature of about 82° F. After 7 days when the plumules were about 4 inches tall records were made of kernels showing a strong germination, dead kernels, and disease infection.

An arbitrary range for the class called "strong" had to be set up. The 7.7% strong plants (Table 1) for the milk stage were all at the lower end of this range, and thus even those classed strong did not average so strong as those of the later groups. The same was true, but to a less extent, for the late milk stage. Perhaps a more accurate picture of vigor would be the dry weight of the plumules and roots produced. Such a measure was used by Tascher and Dungan (10) with the corn harvested in 1924. The dry weight in grams of sprouts per kernel for the various stages of maturity were found to be milk, 0.0354; glaze (late milk), 0.0419; dent, 0.0493; and mature, 0.0526. Only ears that showed 100% germination and relative freedom from disease in a previous germination test were used for this purpose and it is likely that the differences would have been somewhat greater if the entire lot had been used.

Water imbibition and germination were more rapid in the milk stage than in the dent stage, and more rapid in the dent stage than in the mature stage (2). It has been reported (1) that the germ absorbs water more quickly during the first 24 hours than the endosperm. In proportion to size of grain, however, the germ of immature seed is no larger than in mature seed (6). One of the reasons for more rapid imbibition and quicker germination probably lies in the difference in endosperm (10). There may also be another factor, for Wolfe (11) found that from the same ear the small kernels germinated more rapidly than the larger ones. The reason for this was not discovered. This advantage, however, was only temporary in the present experiments for the seedlings from the more mature corn with more horny endosperm surpassed the others in a few days in respect to vigor.

There was a high percentage of dead kernels in both the milk and husking stages (Table 1). The distribution, however, was different in that the dead kernels were distributed over more ears in the milk stage than in the husking stage. Practically no entirely dead ears were found in the milk stage, while this occurred now and then in the husking state. The percentage of germination in the late milk, dent, and mature stages was high and agrees very well with similar data presented by Kiesselbach (6). He made no tests of stages comparable to the milk and husking in these experiments. Duncan and

Marston (3) state that they obtained 100% germination with corn harvested in the milk, soft dough, and hard dough stages. Their descriptions of these stages are very meager and so direct comparisons with the work of other investigators cannot be made.

The annual variations for percentages of strong and dead plants were greater for the husking stage than for any other stage. Comparisons with the mature stage for strong germinations are shown in Fig. 1, and for dead kernels in Fig. 2. There were especially marked depressions in percentages of strong plants in the husking stage in

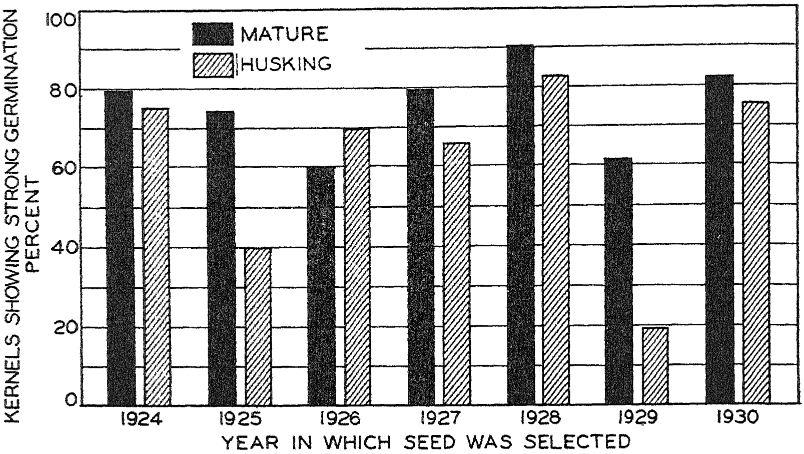

FIG. 1.—Percentages of kernels in different years exhibiting strong germinations in a germinator; seed harvested when mature in comparison with that left in the field until husking time 6 weeks later.

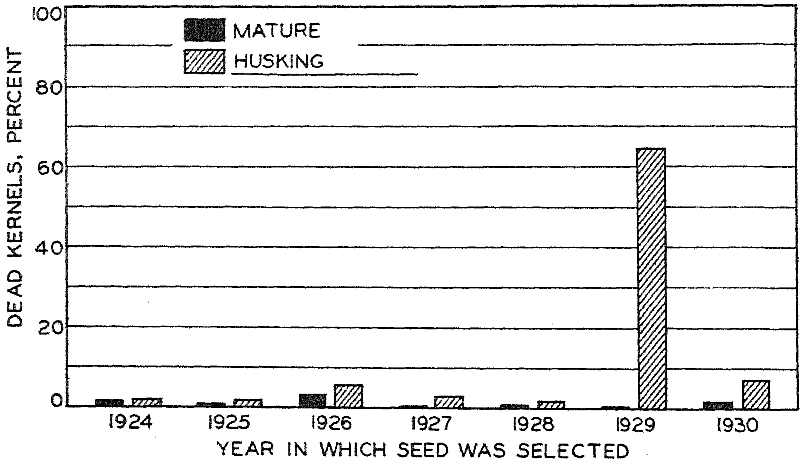

FIG. 2.—Seasonal variations in percentages of dead grains as shown by a germination test of seed gathered at husking time in comparison with seed harvested as soon as mature.

seed selected in 1925 and 1929. When planted the next year, this condition had a decided effect on the yield (Fig. 3). The high percentage of dead kernels in seed selected in 1929 (Fig. 2) was caused by the abnormally low temperatures of —1° F on November 27, and —2° F on November 28 before being harvested. The average moisture content of the grain at this time was approximately 26%. In interpreting the yield data (Fig. 3), however, it should be borne in mind that no ears showing any dead kernels in a 10-kernel test were used for seed.

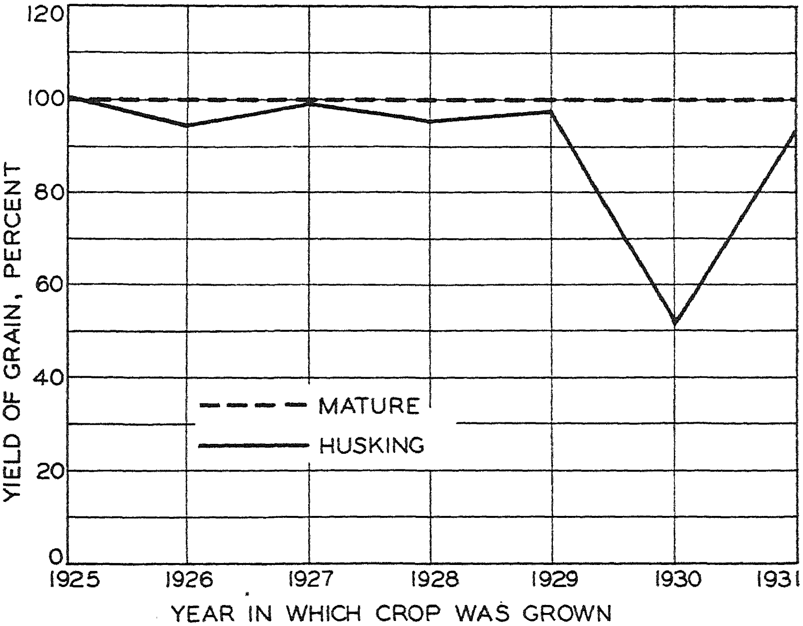

FIG. 3.—A 7-year comparison of yield per acre from seed corn gathered at husking time and seed harvested as soon as mature, taking the latter as 100%. In 1926, 1930, and 1931, the differences were great enough to be statistically significant.

DISEASE INFECTIONS REVEALED BY GERMINATION TEST

That certain fungous infections of seed corn which become visible during the germination test are of some importance as seedling diseases is well established and the literature on the subject has been discussed to some extent in another publication (8). Infections may be divided into two classes, namely, (a) those which are more or less internal, having been acquired primarily before harvesting, and are caused by organisms classed as facultative saprophytes or parasites; and (b) infection from surface-borne spores of organisms classed as saprophytes. Of the latter class, Rhizopus species gain entrance only after the seed coat has been broken by the plumule or radicle or by mechanical injury, and only when the kernel does not have enough resistance to prevent invasion. This resistance, which seems to be chemical in nature, appears rather late in the developing kernel and is influenced by hereditary factors and environmental conditions during maturation of the seed. Its effects are known as Scutellum rot (7). Penicillium and Aspergillus species enter germinating corn kernels in the same way but in addition they also form growths on and gain entrance through, the spongy tissue at the tip end of the kernel. These infections, especially Penicillium species, ran fairly parallel with Rhizopus infection with respect to maturity of seed and were partly covered by it and so no definite notes on Penicillium and Aspergillus infections were made.

Only a small percentage of Penicillium and Aspergillus, principally Penicillium, was internally borne. All Rhizopus infections and about 95% of Penicillium and Aspergillus infections found by the writers could be avoided by surface sterilizing the corn and germinating under aseptic conditions. The internal infections of class A are not prevented by surface sterilizing, except that it has been observed that infections with *Cephalosporium acremonium* frequently are reduced to some extent by disinfecting with mercuric chloride or chlorinated lime.

Infections with *Fusarium moniliforme*, *Diplodia zeae*, and *Gibberella saubinetii* occurred as early as the milk stage (Table 2). The percentage of infection with the first two of these organisms increased as time went on. The most pronounced increase, on the average, was from the dent to the mature stage, not from the mature to the husking stage. Of course, there were seasonal variations, an exception occurring in 1927 when Diplodia infection increased most between the mature and husking stages.

TABLE 2.—*Disease infection that developed during the germination test in yellow dent seed corn harvested in different stages of maturity, 7-year average, 1924–30, Urbana, Ill.*

Stage of maturity of seed	Average harvesting date	Disease infection				
		F. moniliforme %	*C. acremonium* %	*D. zeae* %	*G. saubinetii* %	Scutellum rot %
Milk.....	Aug. 19	5.6	0	0.4	0.2	71.2
Late milk	Aug. 27	7.2	0	0.7	0.1	62.5
Dent....	Sept. 6	7.8	3.9	0.5	0	42.9
Mature..	Oct. 13	10.6	6.9	1.9	0	24.1
Husking.	Nov. 30	10.5	8.3	2.1	0.3	21.3

Infection with *Cephalosporium acremonium* was not found at all in the milk and late milk stages. As this fungus is very delicate and as Rhizopus developed very abundantly on most of the kernels of these early stages, the work was rechecked by surface sterilizing and plating the kernels on sterile media. *C. acremonium* developed very nicely from some of the more mature corn but never from the early stages.

Susceptibility to scutellum rot was greatest in the milk stage, averaging 71.2% of the kernels but gradually decreasing to 21.3% in the husking stage. Corn of the mature and husking stages was very nearly equally resistant. As the development of scutellum rot on the germinator was found to be most commonly caused by *Rhizopus tritici* (7), the test for susceptibility was not left to chance infection, but after the kernels had been placed on the germination tray they were sprayed with a spore suspension of this fungus.

FIELD STAND AND YIELD OF GRAIN

Even though only seed from ears having 100% germination in a 10-kernel test in a germinator was used for planting, wide differences in stand occurred in the different groups (Table 3). Plantings were made at the rate of three kernels per hill and after the plants came up there was no adjustment to uniform stand. From a practical viewpoint, the ability of seed to produce a good stand is of great importance and this effect on yield would have been lost if the stands had been altered. Just what would have happened if the immature groups had been planted enough thicker so as to produce about the same number of plants per unit area as the mature is not known. It would have been desirable to have had parallel tests in which uniform stands had been provided in order to test the effect of maturity of the seed planted on test weight per bushel and rotten and damaged corn. With respect to acre yield from uniform stands, Kiesselbach (6) found that the yield from late milk was only slightly less than from the mature when the stands were the same.

TABLE 3.—*Field stand, rotten corn, and acre yield of yellow dent corn grown from seed harvested in different stages of maturity, 7-year average, 1925–1931, Urbana, Ill.*

Stage of maturity of seed	Field stand %	Rotten corn %	Acre yield, bu.	Loss in yield as compared with mature stage		Odds of probability
				Bu.	%	
Milk.....	52.8	7.7	39.0	18.5	32.2	255:1
Late milk	63.9	6.9	45.8	11.7	20.4	142:1
Dent....	89.4	5.9	55.7	1.8	3.1	16:1
Mature..	91.4	5.7	57.5	0.0	0.0	——
Husking .	80.1	6.0	52.1	5.4	9.4	10:1

Poor stands from the milk and late milk stages were unquestionably caused by the poor vigor of the seedlings; many were not able to make their way up through the ground. The explanation for the poor stand in the husking stage is not so evident for the ears selected for planting appeared on the germinator to possess ability for strong germination. It seems likely that in some years cold weather had caused injury in addition to that which could be observed in the germination test.

The figures on yield are based on total yield including rotten corn. If only sound corn had been considered the differences would have been slightly greater.

The yields varied in the same way as the stand but not quite to the same degree (Table 3). In groups where poor stands occurred the actual yield per plant was greater than in the mature group where the acre yield was best. This can readily be accounted for by the increased opportunity per plant for nutrition and moisture where the stands were thin. The test weight per bushel of grain secured was practically the same for all groups. This also may possibly have been influenced by increased opportunity of plants where the stand was thin.

As practical seed corn selection is confined to the dent, mature, and husking stages, they are of special interest. It was found that there is only little difference in the results from the dent and mature stages, but wider difference between the mature and husking stages, and so the latter should be examined more closely. Only in 1925 did the husking stage yield as well as the mature, and in 1927 it did almost as well (Fig. 3). In the other years there was a noticeable lag in yield from seed selected in the husking stage and in 1930 the reduction was very marked. This coincides with a seed exposure to unusual low temperatures before husking in the previous fall as already mentioned in the section under laboratory germinations. The yearly reduction in stand of the husking stage as compared with the mature followed the yield curve fairly closely, the principal exception having been in 1931 when the stands were equally good but when there was a significant difference in yield.

In terms of odds of probability (Table 3), the difference in yield between the mature and husking stages in a 7-year average would not appear to be significant. This is because the result is affected very differently by different seasonal conditions. When calculated on an annual basis the odds were large enough to be significant (greater than 30:1) in three different years.

SUSCEPTIBILITY TO SEEDLING DISEASES

Disease infections showing on the germinator have already been discussed. The present section is concerned with pure-culture inoculations with certain fungi at planting time on corn representing approximately the best 50% of the ears originally selected. This selection was made on the basis of vigor and relative freedom from disease infection in a germinator. All the fungi used sporulated freely on potato dextrose agar and the inoculations were made by soaking the seed for a few minutes in an aqueous spore suspension immediately before planting.

The names of the fungi used and the results are given in Table 4, and they are given in the order of their severity in reducing yield. As the results from inoculations do not cover the same years and as the effectiveness of these organisms in causing seedling diseases depends on temperature, moisture, and soil conditions, it is not entirely fair to compare the results of one organism with another. For each organism, however, the results with respect to maturity of seed are strictly comparable and involve eight replications of field plats each year. Without exception, each of the fungi used caused most loss when applied to immature seed and had the least effect on mature seed. This agrees with results secured for *Gibberella saubinetii* by Hoppe, Holbert, and Dickson (4).

TABLE 4.—*Effect of corn seed inoculation with several fungi on field stand and acre yield of the resulting crop, the seed having been selected in different stages of maturity, Station Farm, Urbana, Ill.*

Years in which test was made	Stage of maturity of seed	Average field stand %		Average acre yield, bu.		Average decrease in acre yield		Odds of probability
		Control	Inoculated	Control	Inoculated	Bu.	%	
				P. oxalicum				
1930, 1931	Milk.....	71.6	55.7	50.2	39.7	10.5	20.9	9999:1
	Late milk.	81.6	69.6	52.4	42.6	9.8	18.7	9999:1
	Dent.....	92.2	83.2	55.5	48.3	7.2	13.0	9999:1
	Mature...	90.1	84.7	59.6	52.4	7.2	12.1	9999:1
				G. saubinetii				
1929, 1931	Milk.....	58.6	55.5	35.2	31.2	4.0	11.4	2266:1
	Late milk.	73.4	70.1	44.4	39.0	5.4	12.2	4999:1
	Dent.....	86.8	81.4	65.1	62.0	3.1	4.8	331:1
	Mature...	90.3	90.2	69.9	66.3	3.6	5.2	277:1
				A. niger				
1925, 1928 and 1931	Milk.....	65.0	60.3	45.4	42.4	3.0	6.6	7710:1
	Late milk.	70.1	65.3	47.3	45.1	2.2	4.7	336:1
	Dent.....	90.5	85.6	58.7	56.1	2.6	4.4	166:1
	Mature...	91.7	90.5	59.0	56.8	2.2	3.7	166:1
				A. flavus				
1926, 1931	Milk.....	62.9	59.7	47.3	45.2	2.1	4.4	15:1
	Late milk.	76.0	76.1	52.7	50.5	2.2	4.2	76:1
	Dent.....	85.9	83.6	56.5	56.1	0.4	0.7	2:1
	Mature...	87.7	87.5	60.6	59.0	1.6	2.6	8:1
				P. notatum				
1928, 1930	Milk.....	64.9	68.5	47.7	46.0	1.7	3.6	25:1
	Late milk.	71.6	72.8	47.0	45.5	1.5	3.2	31:1
	Dent.....	95.9	96.3	58.9	57.2	1.7	2.9	11:1
	Mature...	96.1	96.4	59.8	60.6	+0.8	+1.3	4:1

Inoculations with *Penicillium oxalicum* were made from a culture supplied by Miss Helen Johann (5). This organism caused very severe losses in yield. More recently the writers have made numerous isolations of *P. oxalicum* from germinating corn and the majority of these were found to be just as detrimental to corn seedlings as the isolations here used. This fungus caused a pronounced loss in stand and a marked depression in vigor. The reduced vigor was so pronounced that with the exception of the milk stage, the percentage loss in yield was considerably more than the percentage loss in stand. In other words, in the inoculated plats the actual yield per plant was less in spite of the reduced stand.

A number of other Penicillium species commonly cause fructification on the tip ends of germinating corn kernels. Among these is *Penicillium notatum*. This is not an oxalic acid producer and has proved comparatively harmless, being at the bottom of the list in Table 4.

Gibberella saubinetii is a common pathogen of a number of cereal crops (8) and the literature will not be reviewed here. The culture used for inoculation had been isolated from a scabby barley kernel. Search was made for a culture that sporulates freely. None such has so far been isolated by the writers from infected corn ears, although numerous isolations were made.

Here again seed inoculation caused a reduction in stand and a considerable depression in vigor so that, with one exception, the percentage loss in yield was greater than the percentage loss in stand.

Aspergillus niger caused a reduction in stand parallel with *Gibberella saubinetii*, but the reduction in yield was not so marked. On nutrient medium this fungus produces calcium oxalate crystals about as abundantly as *Penicillium oxalicum*. The above-ground symptoms of plants affected by these two fungi are similar, except that with *A. niger* the effect is in a milder form.

Aspergillus flavus has a detrimental effect, but just how it operates is not yet known. On high-quality mature seed of the utility type, with sound seed coats, the effect was negligible, while with immature seed of this type there was just a little loss. In other experiments it was found that when the pericarp is broken this fungus inhibits chlorophyl formation in a very marked way so that some plants appear as nearly perfect albinos and others exhibit various degrees of virescence. In experiments in which the seed coat had been injured there was very little initial loss in stand, but many of the seedlings died several weeks after emergence, partly no doubt because of lack of chlorophyl.

SUSCEPTIBILITY TO EAR ROTS

Ear rots found in this experiment consisted chiefly of *Diplodia zeae* and *Fusarium moniliforme* infections. *Basisporium gallarum* played a minor part and *Gibberella saubinetii* still less. Separate data for each kind of rot were not secured. The percentages of ear rot as shown in Table 3 were based on weight. When more than 10 kernels showed rot the ear was classed as rotten, except that when the rot occurred entirely at one end of an ear the ear was broken and only the defective end classed as rotten.

The data in Table 3 suggest that one might expect slightly more rotten corn from immature seed. In 1928 and 1929 the differences in percentage of rotten corn in plants grown from the milk and late milk stages, on the one hand, and the mature stage, on the other, were large enough and consistent enough so that the odds of probability were high. In other years the odds were less than 30:1 and in 1925 and 1927 there was no increase in rotten corn from immature seed.

The stand averaged considerably less where immature seed was used and this too may possibly have had an effect on the development of ear rot. Other data secured by the writers indicate that other things being equal, a thin stand would not favor increased development of ear rot. This factor needs more thorough investigation.

CONCLUSIONS

In case of emergency, seed corn may be harvested as early as 20 days after fertilization when the kernels have attained less than one-third of the dry weight they would attain if allowed to mature, with fairly good assurance that it will perpetuate itself if handled carefully. Such seed, however, cannot be expected to give as good results as mature seed with respect to field stand, disease resistance, or acre yield.

In ordinary practice, it would seem best to pick the seed corn before there is danger from cold weather, regardless of the condition of the corn with respect to maturity. Since mature seed proved to be of greatest value for best all-around results, the farmer will find it advisable to use such strains of corn as will mature properly under his conditions in an average season. It should be pointed out also that during exceptional seasons when it seems advisable to gather seed corn while immature, the seed coat is more easily injured by rough handling. Other experiments under way show that such injuries are very undesirable. Furthermore, it is more important to provide proper curing conditions for corn high in moisture than for corn low in moisture.

SUMMARY

1. Seed corn was selected and harvested in different stages of maturity ranging from about 20 days after fertilization until 6 weeks after maturity for a period of 7 years. Physical data covering moisture content, average weight per kernel, specific gravity, and test weight per bushel are given.
2. Laboratory germination tests showed approximately 10% dead kernels in the first and last groups selected. In the other groups germination was much better. Seedling vigor was much better in the more mature stages than in milk and late milk stages.
3. Seed infections with *Fusarium moniliforme*, *Diplodia zeae*, and *Gibberella saubinetii* were present in the milk stage and with the first two organisms mentioned, the percentage of infection increased progressively until the mature stage. There was an important increase from the dent to the mature stage, but there was on the average no significant increase after the mature stage. *Cephalosporium acremonium* was entirely absent in the first two groups selected, but appeared in groups harvested later. Susceptibility to scutellum rot was greatest in the most immature stage and diminished progressively with later stages.
4. Field stand varied directly with the vigor of the seed planted even though only ears showing 100% germination in a laboratory test were used. The stand was allowed to remain unaltered and the acre yield varied directly with the stand, the mature stage producing the best stand and yield. Corn selected at husking time was as good as that harvested as soon as mature in some years, but not in others.
5. Seed inoculation at planting time with several fungi capable of causing seedling disease in all cases had the greatest effect on immature seed.

6. Ear rots were in some seasons apparently most severe in plants grown from immature seed.

LITERATURE CITED

1. Babcock, S. M. Metabolic water: Its production and rôle in vital phenomena. Wis. Agr. Exp. Sta. Res. Bul. 22. 1912.
2. Dungan, G. H. Some factors affecting the water absorption and germination of seed corn. Jour. Amer. Soc. Agron., 16:473–481. 1924.
3. Duncan, J. R., and Marston, A. R. The effect of different temperatures in drying seed corn of different stages of maturity, on germination. Mich. Agr. Exp. Sta. Quart. Bul., 8:66–68. 1925.
4. Hoppe, P. E., Holbert, J. R., and Dickson, J. G. The relation of maturity of seed to seedling-blight susceptibility in dent corn. Phytopath., 22:12. 1932.
5. Johann, H., Holbert, J. R., and Dickson, J. G. Further studies on Penicillium injury to corn. Jour. Agr. Res., 43:757–790. 1931.
6. Kiesselbach, T. A. Corn investigations. Nebr. Agr. Exp. Sta. Res. Bul. 20:128–129. 1922.
7. Koehler, B. Studies on the scutellum rot disease of corn. Phytopath., 17:449–471. 1927.
8. ————, and Holbert, J. R. Corn diseases in Illinois. Ill. Agr. Exp. Sta. Bul. 354. 1930.
9. Lampe, Lois. A microchemical and morphological study of the developing endosperm of maize. Bot. Gaz., 91:337–376. 1931.
10. Tascher, W. R., and Dungan, G. H. Seedling vigor and diastatic activity of dent corn as related to composition of endosperm and stage of maturity. Jour. Amer. Soc. Agron., 20:133–141. 1928.
11. Wolfe, T. K. A study of germination, maturity, and yield in corn. Va. Agr. Exp. Sta. Tech. Bul. 30. 1927.

A SOIL HYGROMETER FOR IRRIGATED CANE LANDS OF HAWAII[1]

A. Floyd Heck

The sugar planter in Hawaii is continually beset by the problem of when to irrigate and why. The characters of Hawaiian soils, together with those of the cane plant, make the answer to this question somewhat uncertain. It has been found that when the moisture content drops to a certain point the cane practically ceases to grow until it receives additional water. The moisture content of the soil at which growth slows up varies with the different soils and also with different varieties of cane.

When a soil is saturated with water its affinity for water is satisfied, and under these conditions will show no additional attraction for water. As the free water disappears by drainage and the soil becomes drier, it exhibits an attraction for water in inverse relation to the amount of water which it contains. This is not a straight-line function of the moisture content, but as the soil becomes drier its attraction for water increases much more rapidly than the moisture decreases. It has been found that when this attraction of the soil for moisture reaches a point equivalent to from 25 to 40 cm of mercury, it is difficult for the plant to obtain water sufficiently rapid for active

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[1] Contribution from the Department of Soils, Wisconsin Agricultural Experiment Station, Madison, Wis. Received for publication May 4, 1933.

growth, and as a result its growth becomes slower or may even stop. Working on this principle, an instrument, similar to the one described by Heath,[2] has been devised to indicate the changes in the moisture content of a soil in the field.

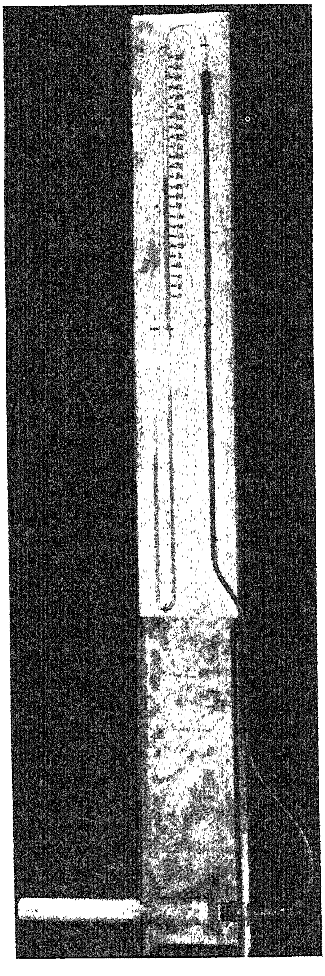

FIG. 1.—The soil hygrometer assembled and graduated in centimeters of mercury.

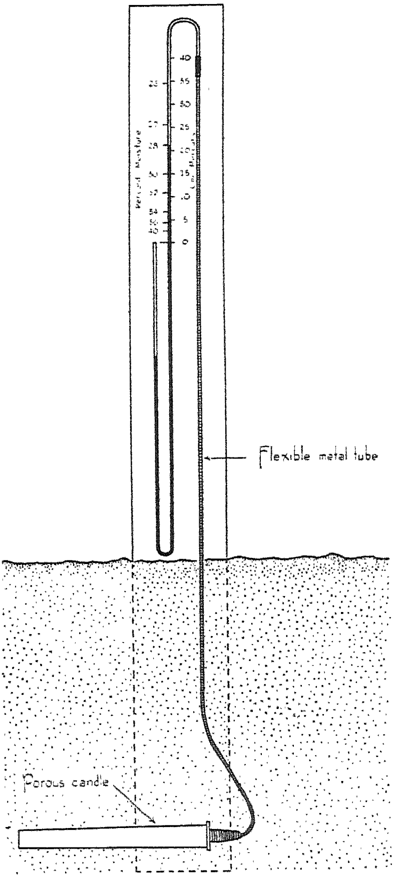

FIG. 2.—Detailed sketch of the soil hygrometer calibrated to read both in centimeters of mercury and in percentage of moisture for an Hawaiian soil from the Waipio Substation.

THE INSTRUMENT

The instrument used for detecting these moisture changes is shown in Figs. 1 and 2. It is made by attaching a mercury manometer about

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[2] HEATH, O. M. S. A method of water control for sand culture. Ann. Bot., 43:71–79. 1929.

50 cm long to a clay filter candle having very fine pores. The candle and the entire system between the candle and the mercury is filled with water which has been boiled to remove all dissolved gases. Care is taken that all air is excluded from the system when the instrument is assembled. It is also necessary that all joints be absolutely tight. The candle and the manometer are conveniently joined with small copper tubing. The whole system may then be mounted on a rigid metal frame a little over 3 feet long, so that the candle may be placed at a depth of about 12 inches, allowing about 2 feet of the frame which carries the manometer to protrude above the soil.

CALIBRATION

The zero point is determined by immersing the candle in water and marking the mercury level on the arm of the manometer attached to the porous candle. This arm of the manometer is then calibrated in centimeters up from the zero point. For ordinary field work this calibration is sufficient, for when the soil has a pull equivalent to 25 or 30 cm of mercury it becomes difficult for the plant to obtain water sufficiently rapid for good growth. If, however, it is desired to calibrate the instrument to read in percentage of soil moisture, it will be necessary to calibrate it in each particular soil in which it is to be used, for soils vary greatly in their relation to water. To make this calibration, the candle of the hygrometer is buried in the soil in which the moisture content is held constant, and after the instrument has come to equilibrium, the height of the mercury is read and the soil moisture accurately determined. A series of these determinations is made, ranging from 2 or 3 to 40 cm of mercury, and the curve for soil pull constructed as shown in Fig. 3. From this curve the moisture percentages may be transferred to the mercury column, so that the percentage of moisture in the soil may be read direct.

USE OF THE INSTRUMENT

This instrument is not entirely fool proof, for if the soil is allowed to become too dry the mercury will either be pulled over into the porous candle, or if the mercury column is long enough to prevent this, the very great attraction of the soil for water will draw the film so thin in the pores of the candle that air will be allowed to enter and thus break the water column between the mercury and the walls of porous candle. In growing cane, with the porous candle set at a depth of 12 inches, there should be little danger from this source until the irrigation water is entirely shut off during the ripening period. In this case it would be wise to remove the instrument, and place it in moister soil.

This instrument was designed primarily for use in controlling the moisture content of soils used in experimental work, both in lysimeters and in small field plats, and has served this purpose so well that it is felt it may be of value in the field as an aid in the practical regulation of irrigation. There is doubt as to its value under conditions where the moisture cannot be controlled, because of the possibility of the soil becoming so dry as to result in the breaking of the moisture film in the porous candle.

From Fig. 3 it can be seen that the curve for the soil pull is rather flat below 25 cm of mercury, and in this range the water moves rather easily and gives fairly good growing conditions so far as moisture is concerned. Above this point the curve takes a decided turn upward, which indicates that the water moves with much greater difficulty, and also that the plant must take its water more slowly and with less ease. The curve in this figure is drawn for a soil taken from the Waipio Substation. There are indications that the curves for other soils may vary somewhat from this one, but will take much the same general shape; however, they will shift a great deal in relation to the moisture percentage. The point at which irrigation should take place, as shown by this instrument, will depend much on the depth at which the candle is placed in the soil. The deeper it is placed, the less the readings will fluctuate between irrigations, because of less variation in soil moisture at this depth than nearer the surface. So it appears, in order to get the best results, the bulb should be placed near the bottom of the heavy root zone, or from 9 to 12 inches deep. The hygrometer reading at which the soil moisture reaches the minimum for good growth can be determined by the field man, and irrigation water applied at this time. With the bulb at a depth of about 12 inches, 20 to 30 cm of mercury should be somewhere near the point at which irrigation water should be applied.

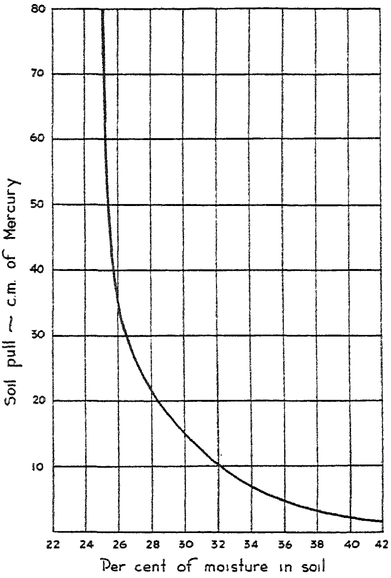

FIG. 3.—Curve showing the relation of the moisture content of a Waipio soil to its soil pull. The moisture percentages in Fig. 2 were taken from this curve.

Working with the cane variety H109 in an undesignated Hawaiian soil, Weller[3] found that when the soil was saturated to its field capacity with water, the cane had a root pressure of 46.7 cm of mercury. When the soil moisture was decreased to a point represented by the moisture contained in the soil under dry field conditions plus 50% of the additional water necessary for saturation to field capacity, the root pressure dropped to 13.5 cm of mercury. Below this moisture content there was little root pressure and at low moisture contents the soil pull became greater than the normal pull of the root for moisture, so that the resulting root pressure even became negative. Thus, as the soil moisture decreases and the soil pull increases, the resultant root pressure decreases so that, as a general expression, the root pressure plus the soil pull tends to equal a constant, or, the root pressure is equal to the root pull minus the soil pull. On this basis, a cane plant having a root pressure of 46 cm in a soil saturated with moisture to field capacity will have a root pressure of only 6 cm when the soil has dried out sufficiently to have a pull of 40 cm of mercury. This root pressure is too low for good growing conditions, and this, coupled with the fact that soils with a high soil pull move water with great difficulty, makes it impossible for cane to grow normally if at all under these conditions. Experience has shown that when the pull of a soil under growing cane reaches 25 to 30 cm of mercury, the root pressure is reduced accordingly, and growth becomes much slower and soon ceases almost entirely. This cessation of growth may be prevented and the cane kept growing normally by irrigation at the proper time, and this time is easily determined by means of the soil hygrometer.

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[3] WELLER, D. M. Root pressure of the sugar cane plant in relation to soil moisture. Rpt. Ass., Hawaiian Sugar Techn., 10th Ann. Meet. 1931.

SUMMARY

A soil hygrometer for the field has been devised to indicate the point at which irrigation should take place.

With the instrument set at a depth of 12 inches, a reading of 20 to 30 cm of mercury indicates the need of more water in the soil.

THE EFFECT OF MONO-, DI-, AND TRICALCIUM PHOSPHATES ON THE REACTION OF SOILS OF DIFFERENT DEGREES OF ACIDITY[1]

W. H. PIERRE[2]

The interest which has recently been shown in the problem of the effect of fertilizers on soil reaction has been confined largely to nitrogenous fertilizers. The relatively little attention given to phosphate fertilizers is probably explained by the fact that most of the phosphorus used in fertilizers has been supplied by one carrier, superphosphate, and that this carrier has not been shown to have any marked effect on soil reaction. In the last few years developments in the fertilizer industry have resulted in the introduction of new phosphate carriers, and also in a modification of the phosphate compounds present in superphosphate as a result of ammoniation. Keenan (5)[3] and Jacob and Ross (4) have shown that di- and tricalcium phosphates are formed along with ammonium sulfate and mono-ammonium phosphate when ammonia is absorbed by superphosphate. The question has arisen as to how effective these phosphates may be in neutralizing the acid-forming property of the ammonium sulfate, and as to how they should be classified as regards their effect on soil reaction (7).

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[1] Contribution from the Department of Agronomy, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director as Scientific Paper No. 129. Received for publication May 27, 1933.

[2] Associate Agronomist.

[3] Numbers in parenthesis refer to "Literature Cited," p. 288.

Although there has been little work on the influence of mono-, di-, and tricalcium phosphates on soil acidity, superphosphate has received considerable study. As shown by Burgess (1), however, some of the work with superphosphate has been contradictory. In general, it has been found to have no appreciable effect, although in many cases slight decreases, and in some cases slight increases, in acidity have been obtained.

Conner (2) was one of the first investigators to study the problem in this country. His work is of special interest because it included studies with mono-, di-, and tricalcium phosphates. As measured by the Hopkins' lime requirement method superphosphate was found to decrease the acidity of the soil when added in amounts less than 4 to 8 tons per acre, while increases in acidity resulted from higher applications. Mono-, di-, and tricalcium phosphates were all found to decrease the lime requirement of the acid soils used in the study. Conner explained his results on the basis that the phosphorus was fixed in the soil by iron and aluminum and that the calcium was thus liberated for neutralization of soil acids. Since it has been shown in recent years (3, 9) that phosphorus fixation in soils is considerably affected by soil reaction, it would seem to follow that the effect of various phosphates on soil acidity might vary with the original reaction of the soil.

The purpose of this investigation was to make a quantitative study of the effect of various phosphates, particularly mono-, di-, and tricalcium phosphates, on soil acidity, and to determine how the results obtained are affected by differences in the original reaction of the soil.

PLAN OF EXPERIMENTS

Two general methods are available in studying the effect of fertilizers on soil acidity, *viz.*, field experiments in which the fertilization is carried on over a period of years, and laboratory or greenhouse experiments in which larger amounts of fertilizer are used over a relatively short period. Both methods offer certain advantages and disadvantages. In field experiments a long-time element is involved, and such controlling factors as soil heterogeneity, downward distribution of acidity, and soil erosion often make quantitative interpretations difficult. For these reasons, carefully controlled greenhouse or laboratory experiments are often to be preferred.

In the present study three large samples of soil with pH values of 4.28, 5.63, and 6.40, respectively, were obtained from different fields of the agronomy farm at Morgantown. The soils varied somewhat in texture but were all of the Dekalb series. After thoroughly mixing and screening each large sample, 30 small samples of 200 grams of dry soil each were placed in tumblers for differential treatments. The treatments given each tumbler are shown in Tables 1, 2, and 3. It will be noted that two rates of each phosphate were used, based on equivalent amounts of phosphorus. Tumblers 25 to 30 received no phosphorus but received calcium carbonate at three different rates in order to make quantitative comparisons of the influence of the phosphates and of calcium carbonate on soil reaction.

The soil in each tumbler was brought to approximately optimum moisture content with distilled water, and more water was added as necessary during the course of the experiment. The soils were allowed to become fairly dry occasionally before adding more water in an effort to simulate field conditions as much as possible. Samples of soil were removed after 6 weeks, 1 year, and 1½ years for determinations of pH, and also at the last sampling for determinations of nitrates and conductivity. The pH determinations were made by the dialysis-colorimetric method (6), except the last determinations on soil 593 and 596, which were made with the quinhydrone electrode with use of a 1 to 2 soil-water suspension. The experiment with soil 596 was started at a later date than those with the other two soils and only two sets of samples were removed and studied.

EXPERIMENTAL DATA

The results obtained with the very acid, medium acid, and slightly acid soils are given in Tables 1, 2, and 3, respectively. It will be noted in Table 1 that all the phosphates studied caused decreases in the acidity of this very acid soil. Dicalcium phosphate, tricalcium phosphate, and monosodium phosphate caused the greatest decreases, while monocalcium phosphate, superphosphate, and rock phosphate caused relatively slight decreases in acidity.

With the medium acid soil, the data of which are reported in Table 2, dicalcium, monosodium, and tricalcium phosphate again were found to cause the greatest decrease in acidity although not to so large an extent as with the very acid soil. As contrasted with the result from soil 508 it is interesting to note that monocalcium phosphate caused no decrease in the acidity of this soil, and that superphosphate caused a very slight increase in acidity as shown by the pH values.

These differences in the action of the different phosphates on soils of different reactions are further shown by the data obtained with the slightly acid soil reported in Table 3. It will be noted that, although tricalcium and dicalcium phosphate showed slight decreases in acidity, monocalcium phosphate caused a slight increase and superphosphate an appreciable increase in acidity when used at the highest rate.

The apparent difference in the effect of monocalcium phosphate and superphosphate on the acidity of these soils was somewhat unexpected. Since a large amount of calcium sulfate is present in superphosphate, however, it would be expected that a high salt concentration would result and that this might be the cause for the relatively low pH values obtained. The specific resistances of the 1 to 5 soil-water extracts were, therefore, determined and are shown in the last columns of Tables 1, 2, and 3. It will be noted that no marked effect on the specific resistance or salt concentration of the extracts was obtained with any of the phosphates except with superphosphate. The latter caused a marked decrease in specific resistance or an increase in salt content especially when used at the high rate. Since an increase in salt concentration of soils causes a decrease in pH values, an attempt was made to bring the soils which had been

TABLE I.—*The effect of different forms and amounts of phosphate compounds on the reaction of a very acid soil (Dekalb loam No. 508).*

No.	Source of phosphate	Rate of phosphate application, lbs. P_2O_5 per acre	$CaCO_3$, lbs. per acre	H-ion concentration			Nitrate* N, p.p.m.	Specific* resistance 25° C, ohms
				After 6 weeks, pH	After 1 year, pH	After 1½ years, pH		
1–2	None	—	—	4.28	4.20	4.20	74	5,040
3–4	Tricalcium phosphate	800	—	4.45	4.40	4.40	86	4,790
5–6	Tricalcium phosphate	2,000	—	4.65	4.60	4.58	105	3,990
7–8	Dicalcium phosphate	800	—	4.63	4.50	4.45	87	5,240
9–10	Dicalcium phosphate	2,000	—	4.93	4.73	4.75	129	3,300
11–12	Monocalcium phosphate	800	—	4.45	4.35	4.35	80	5,370
13–14	Monocalcium phosphate	2,000	—	4.63	4.50	4.45	89	4,450
15–16	Superphosphate	800	—	4.58	4.25	4.30	60	2,315
17–18	Superphosphate	2,000	—	4.50	4.28	4.30	84	1,320
19–20	Monosodium phosphate	800	—	4.63	4.33	4.38	93	4,395
21–22	Monosodium phosphate	2,000	—	5.25	4.80	4.65	126	3,515
23–24	Rock phosphate	800	—	4.40	4.30	4.28	—	—
25–26	Rock phosphate	2,000	—	4.48	4.38	4.38	97	5,065
27–28	None	—	500	4.45	4.23	4.25	83	4,580
29–30	None	—	1,000	4.68	4.40	4.40	85	4,715
31–32	None	—	2,500	5.20	4.85	4.80	109	4,315

*The nitrate nitrogen and specific resistance determinations were made on the 1:5 soil water extracts of the last set of samples removed. Nitrate nitrogen is expressed on the dry soil basis.

TABLE 2.—*The effect of different forms and amounts of phosphate compounds on the reaction of a medium acid soil (Dekalb loam No. 593).*

No.	Source of phosphate	Rate of phosphate application, lbs. P_2O_5 per acre	$CaCO_3$, lbs. per acre	H-ion concentration			Nitrate* N, p.p.m.	Specific* resistance 25° C, ohms
				After 6 weeks, pH	After 1 year, pH	After 1½ years, pH		
1–2	None	—	—	5.63	5.50	5.33	119	3,375
3–4	Tricalcium phosphate	800	—	5.68	5.58	5.36	149	2,995
5–6	Tricalcium phosphate	2,000	—	5.75	5.60	5.45	135	3,020
7–8	Dicalcium phosphate	800	—	5.80	5.63	5.56	121	3,040
9–10	Dicalcium phosphate	2,000	—	5.93	5.83	5.83	126	3,420
11–12	Monocalcium phosphate	800	—	5.63	5.50	5.35	120	3,185
13–14	Monocalcium phosphate	2,000	—	5.60	5.43	5.31	127	3,050
15–16	Superphosphate	800	—	5.48	5.38	5.23	124	1,890
17–18	Superphosphate	2,000	—	5.25	5.23	5.11	148	1,120
19–20	Monosodium phosphate	800	—	5.75	5.50	5.38	144	2,820
21–22	Monosodium phosphate	2,000	—	5.88	5.65	5.56	133	2,930
23–24	Rock phosphate	800	—	5.78	5.45	5.34	105	3,635
25–26	Rock phosphate	2,000	—	5.65	5.60	5.39	125	3,090
27–28	None	—	500	5.80	5.63	5.54	110	3,310
29–30	None	—	1,000	5.98	5.80	5.64	123	3,085
31–32	None	—	2,500	6.58	6.10	6.04	154	2,105

*The nitrate nitrogen and specific resistance determinations were made on the 1:5 soil water extracts of the last set of samples taken. Nitrate nitrogen is expressed on the dry soil basis.

TABLE 3.—*The effect of different forms and amounts of phosphate compounds on the reaction of a slightly acid soil (Dekalb loam No. 596).*

No.	Source of phosphate	Rate of phosphate application, lbs. P_2O_5 per acre	$CaCO_3$, lbs. per acre	H-ion concentration: After 6 weeks, pH	H-ion concentration: After 1 year, pH	Nitrate* N, p.p.m.	Specific* resistance 25° C, ohms
1–2	None	—	—	6.40	6.22	79	4,980
3–4	Tricalcium phosphate	800	—	6.38	6.37	63	5,580
5–6	Tricalcium phosphate	2,000	—	6.40	6.62	57	5,580
7–8	Dicalcium phosphate	800	—	6.43	6.32	75	5,040
9–10	Dicalcium phosphate	2,000	—	6.40	6.46	61	7,075
11–12	Monocalcium phosphate	800	—	6.30	6.25	62	6,555
13–14	Monocalcium phosphate	2,000	—	5.95	6.09	54	7,150
15–16	Superphosphate	800	—	5.95	6.16	69	2,370
17–18	Superphosphate	2,000	—	5.65	5.70	93	1,400
19–20	Monosodium phosphate	800	—	6.35	6.28	64	5,450
21–22	Monosodium phosphate	2,000	—	6.40	6.27	71	4,425
23–24	Rock phosphate	800	—	6.25	6.35	61	6,085
25–26	Rock phosphate	2,000	—	6.18	6.26	71	5,450
27–28	None	—	500	6.43	6.35	68	5,450
29–30	None	—	1,000	6.53	6.61	55	6,020
31–32	None	—	2,500	6.65	6.84	95	4,350

*The nitrate nitrogen and specific resistance determinations were made on the 1:5 soil water extracts of the last set of samples taken. Nitrate nitrogen is expressed on the dry soil basis.

treated with large amounts of superphosphate to a salt content similar to that of the untreated soils and of those receiving high amounts of monocalcium phosphate, in order that a better comparison might be obtained. The method of Volk and Truog (10) was used, in which the soil is leached and a uniform amount of calcium chloride added. The pH values of the soils and the specific resistance of the calcium chloride extracts are given in Table 4.

TABLE 4.—*The reaction of soils as affected by monocalcium phosphate and superphosphate after leaching and treatment with calcium chloride.**

No.	Source of phosphate	Soil No. 508		Soil No. 593		Soil No. 596	
		pH	Specific resistance 25°, ohms	pH	Specific resistance 25°, ohms	pH	Specific resistance 25°, ohms
1–2..	None..................	4.21	642	5.37	634	6.13	652
13–14	Monocalcium phosphate	4.40	637	5.38	632	6.03	662
17–18	Superphosphate........	4.48	527	5.26	521	5.81	571

*Method of Volk and Truog (10) used.

The data for soils 593 and 596 are of particular interest. Although the differences in pH values are not as great as they were previous to the treatment, the soils which received superphosphate still gave lower pH values than those receiving monocalcium phosphate. It will be noted, however, that the effect of the calcium sulfate present in superphosphate still manifests itself by causing a higher salt concentration. Since under field conditions smaller amounts of fertilizer are used at any one time and leaching of soluble salts such as calcium sulfate readily takes place, it is believed that the data obtained from monocalcium phosphate are more typical of the action of superphosphate under field conditions than are the results obtained here with superphosphate.

The low neutralizing action of rock phosphate found is in agreement with the results obtained by Smith, *et al.* (8) and by others, and no doubt is due to its low solubility in the soil. The lower solubility of tricalcium than of dicalcium phosphate may also explain the greater basic effect of the latter. It is probable that over a longer period of time the basic action of tricalcium phosphate and of rock phosphate would become more evident.

As previously mentioned, the object of determining the effect of different amounts of calcium carbonate on the pH of each soil was to make possible a quantitative determination of the neutralizing action of the phosphates in terms of calcium carbonate. In Fig. 1 are shown the buffer curves of the three soils toward calcium carbonate both after the 6-week and the 18-month period. The amounts of calcium carbonate which were required to give the same pH values as were obtained from additions of definite amounts of the various phosphates can be gotten by reading directly from the curve. The values for monocalcium and dicalcium phosphate thus obtained are shown in Table 5. In the last column of the table are given the theoretical

TABLE 5.—*The neutralizing values of mono- and dicalcium phosphates as compared with $CaCO_3$ on soils of different degrees of acidity.*

Soil No.	pH of untreated soil		Phosphate fertilizer		Equivalent $CaCO_3$ per ton of fertilizer		
	At beginning	At end	Source	Pounds of P_2O_5 per acre	Found		Theoretical*
					Individual	Average	
508	4.28	4.20	Dicalcium phosphate	800 2,000	1,418 935	1,177	581
596	5.63	5.33	Dicalcium phosphate	800 2,000	608 704	656	581
593	6.40	6.20	Dicalcium phosphate	800 2,000	428 288	358	581
508	4.28	4.20	Monocalcium phosphate	800 2,000	763 459	611	0
596	5.63	5.33	Monocalcium phosphate	800 2,000	0 0	0	0
593	6.40	6.20	Monocalcium phosphate	800 2,000	0 Acid	——	0

*Assuming one-third of the phosphoric acid to be acid-forming.

equivalent basicity values of the phosphates in terms of calcium carbonate based on the assumption that one-third of the phosphoric acid is acid-forming or that monocalcium phosphate has no effect on soil reaction. The data bring out very clearly the fact previously shown that the greater the original acidity of the soil, the more basic is the action of the added phosphates. It will be noted that, with the very acid soil, dicalcium phosphate gives an equivalent basicity about twice as high as the theoretical. This means that at this pH value practically all the calcium in dicalcium phosphate functions in neutralizing the soil acids. Likewise, it is evident that most of the calcium of monocalcium phosphate has been effective in neutralizing soil acids on this very acid soil. With the

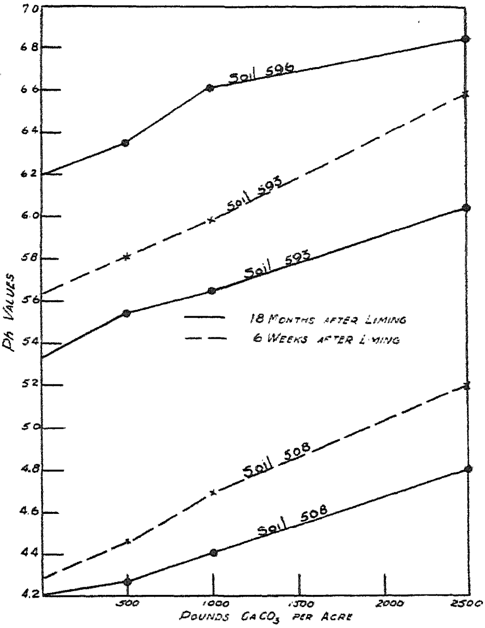

FIG. 1.—Buffer curve of soils used in the study.

medium acid soil of pH 5.33 the theoretical values agree well with those found. Monocalcium phosphate shows no effect on soil acidity and dicalcium phosphate has a neutralizing value approximately equivalent to one-half its calcium content. On the slightly acid soil, however, the values found are lower than the theoretical. This means that less than one-half of the calcium of dicalcium phosphate functioned in neutralizing soil acids and that monocalcium phosphate was slightly acid-forming.

In an investigation of the changes in the pH value of the soils resulting from the addition of the various phosphate compounds, any possible secondary effect of phosphates on soil reaction should be considered. For example, if treatment of the soil with large amounts of phosphate materially increases nitrification of the soil organic matter, an increase of acidity would result and the true basic action of the phosphate would not be readily evident. The nitrate nitrogen contents of the soils at the end of the incubation period were, therefore, determined. The results are given in the second to the last columns of Tables 1, 2, and 3. If the data of soil 593 and 596 are first considered, it will be noted that none of the phosphates, except possibly superphosphate at the higher rate, had any significant effect on nitrification. With the very acid soil (No. 508), however, the large amounts of phosphate caused an increase in nitrification in all cases. This increase in nitrification was due apparently to the higher pH values resulting, for about the same concentration of nitrates was found regardless of whether the rise in pH value was caused by lime or by phosphates. For this reason little or no error resulted from differences in nitrification even in soil 508, if the changes in pH values from phosphate additions are compared with those from liming as was done in calculating the data given in Table 5.

GENERAL DISCUSSION

It is evident from these data that one reason for the conflicting results which have been reported regarding the action of superphosphate on soil acidity is the difference in the original reaction of the soils used by the different investigators. It has been shown in the present study that the greater the acidity of the soil, the more basic is the action of the different phosphates. This is apparently due to differences in the reactions involved when phosphorus is fixed in soils of different degrees of acidity.

In some recent very interesting investigations Teakle (9) and Gaarder (3) studied the influence of reaction and also cation concentration on the fixation of phosphates in soils. Their results are in good agreement in showing that the solubility of calcium phosphate rapidly decreases as the pH of the soil or solution is raised to about 6.5, whereas the solubility of iron phosphate is at a minimum about pH 3.0 and increases gradually as the acidity is decreased. In very acid soils, therefore, it is apparent that iron, and possibly aluminum, play the leading rôle in relation to phosphorus fixation, whereas in slightly acid or neutral soils fixation as calcium phosphate may become of primary importance. In addition to solubility relationship there is the further fact that, the less acid the soil, the greater the content of calcium in the exchange complex and, therefore, the greater the amount of calcium capable of entering into the fixation reactions.

The manner in which the fixation of phosphorus by soils of different degrees of acidity affects the basic or acidic action of phosphate fertilizers which are applied is readily seen from a consideration of the following equations:

1. $CaH_4(PO_4)_2 + 2Fe(OH)_3 = 2FePO_4 + Ca(OH)_2 + 4H_2O$ (most important at low pH values or at pH 4.5 to 5.0)

2. $CaH_4(PO_4)_2 + 2CaX = Ca_3(PO_4)_2 + 2H_2X$ (of greatest importance above pH 6.0)

In these equations X represents the complex anion with which the exchangeable bases and hydrogen are combined, and $Fe(OH)_3$ represents primarily the hydrated oxides of iron, although aluminum may possibly act in a similar manner. It will be noted that, if the phosphorus of monocalcium phosphate is fixed according to reaction or equation 1, calcium hydroxide is liberated and will function in reducing soil acidity. On the other hand, if the phosphorus is fixed according to equation 2, the hydrogen of monocalcium phosphate replaces calcium in the exchange complex and thus increases the acidity of the soil. On very acid soils, or at pH values of about 4.5 to 5.0, reaction 1 is predominant. As the acidity is decreased, reaction 2 becomes of greater importance and probably assumes the important rôle at pH values slightly above 6.0.

In the case of soil 508 of the present study, which had a pH value of 4.28, at the beginning of the experiment, reaction 1 apparently was of primary importance since the decrease in soil acidity found was approximately equivalent to the $Ca(OH)_2$ formed according to this equation. With soil 596, which had an original acidity of pH 6.40, fixation probably took place largely according to equation 2. Since the increase in acidity found was lower than would be obtained if all the phosphorus were fixed according to equation 2, however, some fixation probably also took place according to equation 1. With soil 593, which had an original pH of 5.63, both reactions probably were more equally involved, with the result that there was no effect on soil acidity from the addition of monocalcium phosphate.

The differences in the effect of any of the other phosphate compounds on soils of different degrees of acidity can likewise be explained by equations similar to those given for monocalcium phosphate. It is recognized, of course, that the effect of any phosphate on soil reaction may vary somewhat with different soils even if they are of similar pH values, since other factors besides acidity affect phosphorus fixation. Among such factors may be mentioned the nature and amount of iron oxides present in soils, the fixation by other processes than those considered, the amount of phosphate applied, and the length of time allowed for fixation. The last two of these factors are closely related, and are of importance in interpreting some of the conflicting data reported regarding the action of superphosphate on soil reaction. It becomes readily evident, for example, that, if a large amount of superphosphate is applied to a soil and if an insufficient amount of time is allowed for fixation to take place, it will be more acidic than if equilibrium conditions are obtained. This can be seen from a study of the data obtained in this investigation by comparing the action of the phosphates and calcium carbonate after the 6-week and the 18-month period of contact.

SUMMARY

The effect of six different phosphates on the reaction of three soils of different degrees of acidity was studied in small tumblers over a period of 18 months. The changes in pH values after 6 weeks and after 18 months were determined and were compared with the effect obtained by additions of small amounts of calcium carbonate.

It was found that the original reaction of the soil materially influenced the effect of the various phosphates on soil reaction; the more acid the soil, the greater the basic action of the different phosphates or the less their acidic effect.

On a soil of pH 4.28, monocalcium phosphate was found to have a basic action approximately equivalent to its calcium content, whereas on a soil of pH 5.63, it had no effect, and on a soil of pH 6.40 it had a slight acidic action.

The action of superphosphate on the most acid soil was about the same as for monocalcium phosphate, but on soils of the two higher pH values it had a slightly greater acidic action than the latter. This is believed to be temporary and due at least in part to the higher salt concentration in the soil resulting from the calcium sulfate of superphosphate.

Dicalcium phosphate was found to have a basic action approximately equivalent to its total calcium content on the very acid soil of pH 4.28 and to approximately one-half its calcium content on a soil of pH 5.63, whereas it had only a very slight basic action on a soil of pH 6.40.

Tricalcium phosphate showed a slightly lower neutralizing value in the soil than did dicalcium phosphate, possibly due to its lower solubility.

Monosodium phosphate was found to have a greater basic action than monocalcium phosphate, probably as a result of the high content of sodium introduced into the exchange complex.

It is concluded from these results that for most soils of the humid regions, the pH values of which lie mostly between 5 and 6, superphosphate, rock phosphate, and monocalcium phosphate can be considered to have no appreciable effect on soil reaction, whereas hydrated dicalcium and tricalcium phosphate can be considered basic.

The relation between phosphorus fixation and the results obtained in this study are briefly discussed.

LITERATURE CITED

1. BURGESS, PAUL S. The reaction of soils in the field as influenced by the long-continued use of fertilizer chemicals. R. I. Agr. Exp. Sta. Bul. 189. 1922.
2. CONNER, S. D. Acid soils and the effect of acid phosphate and other fertilizers upon them. Jour. Ind. Eng. Chem., 8:35. 1916.
3. GAARDER, TORBJORN. Fixation of phosphoric acid in soils. (Translated title.) Medd. Vestlandets Forstl. Forsoksstat, No. 14, 140. 1930.

4. JACOB, K. D., and ROSS, W. H. Chemical nature and solubility of ammoniated superphosphates and other phosphates. Jour. Amer. Soc. Agron., 23:771–787. 1931.
5. KEENAN, FRANK G. Reactions occurring during the ammoniation of superphosphate. Jour. Ind. Eng. Chem., 22:1378–82. 1930.
6. PIERRE, W. H., and PARKER, F. W. The use of collodion sacks in obtaining clear soil extracts for the determination of water-soluble constituents. Soil Science, 23:13–32. 1927.
7. ————. Determination of equivalent acidity and basicity of fertilizers. Jour. Ind. Eng. Chem., Anal. Ed., 5:229–234.
8. SMITH, F. B., BROWN, P. E., PETERSON, J. B., and Schlatz, F. E. The influence of lime and phosphate fertilizers on soil reaction. Jour. Amer. Soc. Agron., 24:469–476. 1932.
9. TEAKLE, L. J. H. Phosphate in the soil solution as affected by reaction and cation concentration. Soil Science, 25:143–62. 1928.
10. VOLK, N. J., and TRUOG, E. The electrometric determination of the pH of soils with proper regard for the quantity of soluble salts present. Amer. Soil Survey Assoc. Bul. 13:198–202. 1931.

FURROW VERSUS SURFACE PLANTING WINTER WHEAT[1]

T. A. KIESSELBACH and W. E. LYNESS[2]

Considerable interest has developed in the comparative merits of surface and furrow grain drills for planting winter wheat under the soil and climatic conditions of eastern Nebraska. This interest has spread from the enthusiastic adoption of the furrow drill during recent years by many wheat growers in the drier sections of several hard winter wheat states, including western Nebraska, western Kansas, northeastern Colorado, Wyoming, western Texas, and Montana. Furthermore, manufacturers have been divided in their recommendation of furrow drills for eastern Nebraska. Accordingly, tests were undertaken on the Experiment Station farm at Lincoln which were designed to supply the desired information and to account for any differences that might result.

TYPES OF DRILLS TESTED

Furrow drills.—Three standard makes of furrow drills which differed with respect to their mode of seed distribution within the drill row were included in the test each year. One drill dropped the seed in narrow rows which were opened with disks and spaced 12 inches apart. Another was a shoe drill which distributed the seed in rows about 4 inches wide and 14 inches apart. The third opened the furrows with disks spaced 14 inches apart and placed the seed in rows of intermediate width.

These drills were loaned by the manufacturers who cooperated further by having personal representatives assist in seeding the plats during the first year or two.

Surface drills.—For comparison with furrow drilling, wheat was also surface planted with a standard 7-inch disk drill and with a disk alfalfa drill which spaced the rows 4 inches apart.

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[2] Agronomists.

PLAN OF THE EXPERIMENT

A characteristic of furrow drills is a spacing of rows approximately double that of standard 7-inch surface drills. This extra distance is necessary to allow for the required depth and width of the furrow. It is commonly claimed by the manufacturers of furrow drills that little more than half as much seed per acre is required as with surface drills. In order to determine whether a difference in yield from the two types of drills might be due to the furrow, the distance between rows, or the amount of seed, the experiment was made to include both 7-inch and 14-inch row spacing at approximately 3-peck and 5-peck seeding rates per acre.

Although closer drilling than 7-inch rows is uncommon in this territory, drills are on the market which space the rows 4 inches apart. It has been claimed by some manufacturers that greater space than this is not occupied by the plants and that yields are proportionately decreased as the distance is increased beyond 4 inches. Therefore, to complete the drill type comparison, wheat was also sown in these tests by means of a standard 4-inch disk alfalfa drill.

In order to determine just what is gained by way of increased yield from seeding with a drill, broadcast plats sown at three different rates were included.

Since the different drills could not be adjusted to sow at identical rates, they were set as nearly alike as possible and the actual amount of seed used per acre was determined. With some variation, the two rates of planting for each drill approximated 3 and 5 pecks per acre.

The entire series of tests was planted in triplicate field plats that were one drill wide and contained approximately 1/30 acre. Border rows were removed and discarded before harvest in order to avoid the variable border effects associated with the different row spacings.

Yields were based on actual areas harvested. In case of the drilled plats, the width was calculated from midway between the first and second marginal rows on either side of the plat.

RESULTS

The comparative yields of the various tests are reported in Table 1 for the 3-year period, 1930 to 1932. An analysis of the data is summarized below.

Type of furrow drill.—The extreme difference in yield between the three makes of furrow drills was 2.6 bushels for the 3-peck rate and 1.5 bushels for the 5-peck rate. These yield differences did not prove statistically significant, and it is concluded that equal yields might be expected from them at comparable seeding rates.

Rate of seeding with furrow drills.—As an average for the three types of furrow drill, 3 pecks of seed per acre yielded at the rate of 32.5 compared with 36.0 bushels for the 5-peck rate. Evidently, the generally recommended rate of 3 pecks was insufficient and the wheat responded advantageously to 5 pecks per acre just as it did in case of the surface planting in 14-inch rows.

Effect of distance between rows.—Comparing the 7- and 14-inch row spacing of the John Deere surface drill, the 14-inch spacing yielded 5.5 bushels less at the 3-peck rate of seeding and 3.1 bushels less at the

TABLE 1.—*Comparative yields from furrow and surface drilled and from broadcast winter wheat (Cheyenne) in relation to rate of planting and space between drilled rows, 1930–32.**

Planting practices			Crop harvested				
Manner of planting and type of drill row	Space between rows, inches	Seed per acre, lbs.	Ave. wt. per bushel, lbs.	Yield per acre, bu.			
				1930	1931	1932	Ave.
Furrow drilled, narrow row...	12	40	58.2	40.4	31.6	26.1	32.7
Furrow drilled, narrow row...	12	79	58.4	42.0	34.3	29.7	35.3
Average..............................			58.3	41.2	33.0	27.9	34.0
Furrow drilled, medium row..	14	49	58.2	39.3	31.4	30.5	33.7
Furrow drilled, medium row..	14	75	58.6	42.9	33.6	33.8	36.8
Average..............................			58.4	41.1	32.5	32.2	35.3
Furrow drilled, wide row.....	14	45	57.4	37.6	32.0	23.7	31.1
Furrow drilled, wide row.....	14	83	58.1	42.7	35.0	29.7	35.8
Average..............................			57.8	40.2	33.5	26.7	33.5
Surface drilled, narrow row...	14	49	58.7	43.9	36.1	29.9	36.6
Surface drilled, narrow row...	14	75	58.5	44.6	38.8	33.7	39.0
Average..............................			58.6	44.3	37.4	31.8	37.8
Surface drilled, narrow row...	7	49	58.7	49.5	41.0	35.7	42.1
Surface drilled, narrow row...	7	75	58.5	47.4	43.4	35.4	42.1
Average..............................			58.6	48.5	42.2	35.6	42.1
Surface drilled, narrow row...	4	39	58.7	43.0	33.9	26.9	34.6
Surface drilled, narrow row...	4	70	58.9	50.0	38.6	35.8	41.5
Average..............................			58.8	46.5	36.3	31.4	38.1
Broadcast.................	—	49	58.1	39.8	33.2	29.8	34.3
Broadcast.................	—	75	58.5	44.1	34.8	32.3	37.1
Broadcast.................	—	90	58.5	45.0	35.4	32.3	37.6
Average..............................			58.4	43.0	34.5	31.5	36.3
Miscellaneous Comparison with Surface Drill							
No press wheels, normal depth	7	75	—	47.4	43.4	35.4	42.1
Press wheels, normal depth...	7	75	—	47.2	44.0	34.9	42.0
Press wheels, deep drilled.....	7	75	—	46.0	40.7	37.4	41.4

*The annual probable error of any difference in yield as calculated by the variance method was 1.95, 1.23, and 2.22 bu. for 1930, 1931, and 1932, respectively. The corresponding error for the 3-year period was 1.06 bu., and by the formula 3 x PE it is calculated that a difference of 3.17 bu. is necessary for statistical significance.

5-peck rate as an average for the 3 years. From this it seems apparent that wheat is not able fully to occupy the land when the rows are 14 inches apart, and that this helps account for the inferior yields of the furrow drills in these experiments.

As judged by the standard 5-peck rate, the 4-inch spacing of rows with yields of 41.5 bushels per acre proved about equally favorable as the 7-inch rows which yielded 42.1 bushels. In case of the thin rate the yield from this 4-inch drill was inferior.

TABLE 2.—*Detailed development of winter wheat plants grown under various conditions of furrow and surface drilling, 1932.**

Kind of drill	Manner of planting		Crop harvested							
	Space between rows, inches	Seed per acre, lbs.	Plants per foot of row	Heads per plant	Spikelets per head	Fertile spikelets per head	Kernels per head	Kernels per fertile spikelet	Grain per 100 heads, grams	Weight per 100 kernels, grams
Furrow.	14	45	12.4	2.91	15.0	88	28.4	2.16	91.5	3.21
Furrow.	14	79	17.3	2.44	14.9	85	26.3	2.06	86.2	3.33
Average.			14.9	2.68	15.0	87	27.4	2.12	88.9	3.27
Surface.	14	49	13.8	3.04	14.7	86	26.4	2.10	88.6	3.37
Surface.	14	75	15.4	2.95	14.6	82	23.9	2.01	79.8	3.33
Average.			14.6	2.99	14.7	84	25.2	2.06	84.2	3.35
Surface.	7	49	10.9	2.81	14.0	83	24.6	2.12	82.9	3.37
Surface.	7	75	13.6	2.28	13.4	82	21.9	1.99	74.4	3.41
Average.			12.3	2.55	13.7	83	23.3	2.06	78.7	3.39
Surface.	4	39	6.4	3.47	13.9	86	26.8	2.25	88.7	3.31
Surface.	4	70	7.9	2.97	13.6	83	24.5	2.19	85.1	3.48
Average.			7.2	3.22	13.8	85	25.7	2.22	86.9	3.40

*These data are taken from the same triplicated plats reported in Table 1.

Surface vs. furrow drills.—As an average for both seeding rates, the mean yield of the three-furrow drills was 34.3 bushels per acre compared with 42.1 bushels for the standard 7-inch surface drill, and 37.8 bushels for the same surface drill when the rows are spaced 14 inches apart by closing alternate drills. From these results, which are highly significant statistically, it is concluded that the furrow drill is inferior under eastern Nebraska conditions. This inferiority is due to a considerable extent to the unfavorable wide spacing of rows. There appears to be some additional unexplained cause for reduced yield from the furrow drill.

Broadcasting.—The average yield for the three rates of broadcasting was 36.3 bushels compared with 42.1 bushels for the average of two rates with the standard 7-inch drill. The yields for the various seeding rates of 3, 5, and 6 pecks per acre were 34.3, 37.1, and 37.6 bushels, respectively. Thus, the optimum broadcasting rate of 6 pecks yields 4.5 bushels, or 11%, less than the optimum drilling rate.

Variations in mode of surface drilling.—Several departures from the customary mode of 7-inch drilling were included in these tests. The same drill was used throughout, set at 5 pecks per acre. Compared with 42.1 bushels per acre for normal drilling with press wheels attached, the yield was 42.0 bushels with press wheels removed and 41.4 bushels for extra deep drilling to a depth of 3 inches.

Thus, it appears that there may be considerable variation in the manner of surface drilling without a material effect upon yield, providing conditions do not exist which affect the germination of the seed.

RELATION OF PLANT DEVELOPMENT TO MANNER OF PLANTING

In order to determine the character of plant response to the manner of planting, detailed counts and measurements as to stooling and spike and kernel development were made for the 1932 crop. The results reported in Table 2 are based on 10 random 1-foot row sections taken from each individual plat. Thus, since there were three replications, the data for each type of surface drilling represent the averages of 30 such determinations, while those for the averages of the furrow drilling are for 90 separate determinations.

An analysis of the data reveals no striking differences in plant development that cannot be largely accounted for by seeding rate per acre or per foot of row. If furrow and surface planting with similar rate and row spacing are compared, the individual plant development of both is very similar. An increase in seeding rate with both types of drills resulted in an increase in number of plants matured per unit area and somewhat reduced the number of heads per plant. Where equal amounts of seed per acre were sown in rows of various spacings, plant competition appears to have been most severe within the more widely spaced rows which resulted in a lowered percentage of plants becoming established and surviving till harvest.

DIFFERENTIAL VARIETAL RESPONSES OF WINTER WHEAT TO TIME OF PLANTING[1]

C. A. SUNESON AND T. A. KIESSELBACH[2]

Differential varietal responses to the time of planting were so striking in the winter wheat nursery during the season of 1931–32 that the results would seem of interest in connection with the technic of advanced nursery tests. It is well known that varieties frequently differ in their seasonal and regional adaptation to the prevailing environmental conditions. The effect that a mere difference of 2 or 3 weeks in planting date may have upon the relative adaptation of different varieties within a single season has perhaps not been so well appreciated. This has been found to reverse very striking differences in the productivity of some varieties. Many different plant characteristics involved in crop adaptation may be factors in these relations. In this case differential winterhardiness and Hessian fly resistance were of major importance.

METHOD OF TESTING

Twenty varieties or selections were systematically replicated five times at each of three planting dates in nursery plats consisting of three 16-foot rows spaced 12 inches apart. The center row of each plat was harvested for yield. The dates of planting were September 26, October 6, and October 15. Emergence dates were October 2, 13, and 22, respectively. The two extremes in planting date exceeded the normal planting period of this region by only a few days.

RESULTS

Groups of varieties reacted alike to the variable factors of planting date, owing to varietal similarities. We are here interested primarily in differences and these may be illustrated by the variable results obtained with the six varieties reported in Table 1. Under the conditions of these tests these varieties fell into four rather distinct classes, as follows: (1) Nebraska No. 60 and Minturki were winterhardy but rather susceptible to Hessian fly; (2) Tenmarq was both fairly "fly" and cold susceptible; (3) the two Blackhull hybrids were "fly" resistant but lacking in winterhardiness; and (4) Ohio No. 35 was resistant to both "fly" and cold.

The earliest planting date, September 26, somewhat preceded the "fly-safe" date and susceptible varieties sown then became severely infested in the fall. As a consequence of this differential fall infestation with "fly" two effects were noted, *viz.*, (1) the spring survivals of such normally hardy varieties as Nebraska No. 60 and

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[1] Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C., cooperating. Journal Series paper No. 138 of the Nebraska Agricultural Experiment Station. Received for publication May 12, 1933.

[2] Junior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Agronomist, Nebraska Agricultural Experiment Station, Lincoln, Nebr., respectively.

TABLE 1.—*Comparative Hessian fly infestation, winterkilling, and grain yields of six varieties of winter wheat planted at three different dates in the fall of 1931 at the Nebraska Agricultural Experiment Station.*

Date of planting	Variety					
	Ohio No. 35 (Nebr. 2102)	Nebr. 60 (C. I. 6250)	Tenmarq (C. I. 6936)	Kanred x Blackhull (Nebr. 2083)	Minturki (C. I. 6155)	Minturki x Blackhull (Nebr. 2059)
	Number of Hessian Fly Puparia per Plant (Spring Brood)					
Ave., all dates	3.7	20.3	7.8	3.5	9.6	4.5
	Loss of Plants Through Winterkilling, %					
Sept. 26	19	29	54	21	29	28
Oct. 6	15	9	44	47	16	56
Oct. 15	39	15	55	56	20	60
Ave.	24	18	51	41	22	48
	Yield of Grain per Acre, Bu.*					
Sept. 26	42.9	10.5	13.0	46.7	19.2	47.1
Oct. 6	43.8	23.2	20.3	23.9	31.3	19.2
Oct. 15	24.7	14.7	9.3	12.8	22.1	9.7
Ave.	37.1	16.1	14.2	27.8	24.2	25.3
	Rank as to Yield Among 20 Varieties Tested					
Sept. 26	6	15	13	3	10	2
Oct. 6	1	14	17	11	3	20
Oct. 15	2	10	17	14	4	16
Ave.	1	14	17	6	8	7

*The yields are based on middle rows of 3-row plats replicated 5 times. The differences considered necessary for significance (3 x PE_d) as calculated from generalized probable errors of the mean yields are 9.4, 14.0, and 7.8 bushels per acre for plantings on Sept. 26, Oct. 6, and Oct. 15, respectively.

Minturki were on a plane with those of the less hardy Blackhull hybrids, and (2) susceptible varieties that were weakened by the fall brood of Hessian fly were subject to much greater infestation and damage by the spring brood of "fly" than were the same varieties planted after October 1. An average of the 20 varieties in this nursery showed 14 and 9 as the average numbers of spring brood puparia per plant in the September 26 and October 6 plantings, respectively. Ultimate yield differences for this earliest planting date decidedly favor the Blackhull hybrids and Ohio No. 35 and reflect very well their superior fly resistance. The high yields of these varieties suggest that winterkilling was not of great importance in plantings made on this date. The data also suggest that the Blackhull hybrids may have an earlier optimum planting date than the other varieties.

Plantings made on October 6 showed some striking reversals of varietal yields as compared with the previous date, but such shifting of relative yields was most extreme in connection with the last planting date on October 15. The superior winterhardiness of Minturki then became a more important factor in yield than the "fly" resistance of the Blackhull hybrids. The fact that Minturki was paired with these Blackhull hybrids throughout these successive plantings adds to the significance of the reversals shown. In the case of the more "fly" susceptible Nebraska No. 60, statistical yield superiority over the Blackhull hybrids was not attained despite its marked superiority in winterhardiness at the latter date. Adequate resistance to both "fly" and low temperatures permitted Ohio No. 35 to show to advantage in all plantings, while deficiencies in these characteristics gave rise to a continuous series of adverse yields for Tenmarq.

It is rather generally recognized that delays in planting in Eastern Nebraska accentuate winterkilling. Likewise seeding prior to the "fly-safe" date frequently permits a fall "fly" infestation of susceptible varieties. Reduction in spring stand, general weakening of the plant, and increased "fly" infestation in the spring may result.

While some interest attaches to the average results for the three planting dates, the individual results doubtless give the best measure of varietal differences and specific adaptability. The broad objective in advanced testing is an evaluation of the varieties or selections with respect to their specific reactions to various factors of the environment, and plantings at several dates are believed to afford a simple and effective adjunct to such a program.

SUMMARY

Differential varietal responses to time of planting were very pronounced in the advanced winter wheat nursery under conditions of Hessian fly prevalence and winterkilling.

Since changes in the degree of expression of these and other environmental factors which influence the wheat crop occur as a result of change in the time of planting, the introduction of duplicate plantings at several dates is regarded as a valuable adjunct in the technic of advanced testing.

RESISTANCE OF WHEAT VARIETIES TO BUNT AT MOCCASIN, MONTANA, AND NORTH PLATTE, NEBRASKA[1]

J. L. SUTHERLAND AND N. E. JODON[2]

The control of bunt (*Tilletia levis Kühn and T. tritici* (Bjerk.) Wint.) by the production of resistant varieties of wheat has attractive possibilities. The problem is complicated, however, by the fact that there may be several physiologic forms of bunt and that resistance to these various forms must be combined with desirable agronomic characters. The first step in achieving such control is the assembling of information regarding the reaction of varieties believed or known to carry some factors for resistance to bunt. It is highly desirable that the distribution of various physiologic forms of bunt and the reaction of varieties of wheat to each of these forms be determined. Until such information can be secured, it would appear that a knowledge of the relative resistance of important varieties grown in localities where different forms of bunt may be suspected would be of value. If it can be shown that varieties respond substantially alike in different areas, and from season to season, a breeding program may be undertaken with much assurance of success. If, on the contrary, the response of the varieties is not similar, the data secured may provide a sound basis for a study of physiologic forms and of resistance of varieties to these various forms.

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[1] Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Data obtained in cooperation with the Montana and Nebraska Agricultural Experiment Stations. Received for publication May 31, 1933.

[2] Junior agronomists in charge of the cereal experiments of the Division of Cereal Crops and Diseases at the Judith Basin Branch Station, Moccasin, Mont., and the North Platte Substation, North Platte, Nebr., respectively.

The bunt reaction of the principal commercial varieties of winter wheat of the Great Plains and of many other varieties believed to be resistant to one or more forms of bunt has been tested for 4 years at the North Platte Substation, North Platte, Nebr., and for 6 years at the Judith Basin Branch Station, Moccasin, Mont.[3] The purpose of this paper is to present the accumulated data and to interpret them in relation to the problem of producing bunt-resistant varieties for the Great Plains.

MATERIALS AND METHODS

The data from North Platte are from irrigated seedings, irrigation being used to insure moisture conditions favorable for infection. Those from Moccasin are from seedings on clean fallow without irrigation. The varieties have been grown mostly in single or duplicate 16-foot or 8-foot rows, the length and the number of rows varying from year to year. Percentages of infection have usually been based on counts of from 200 to 300 heads; except for Moccasin, in 1927, when the plant was used as the unit. Inoculum for the Moccasin test was originally collected from a field of Turkey wheat near Moccasin, and that for the North Platte test from a collection made in a field of Kanred wheat near North Platte. Subsequently, inoculum was obtained from any smutty material in susceptible varieties at each station. Inoculation at Moccasin has been accomplished by shaking a small quantity of bunt spores with the seed in the seeding envelope at North Platte by rubbing the ground spore material and the seed together between the hands. Seeding was done at Moccasin at the normal time, the dates varying from August 24 to September 28. At North Platte, seeding has been delayed until two or three weeks after the normal date, or until about October 10, to secure lower and more favorable temperatures for infection.

EXPERIMENTAL RESULTS

The percentages of bunt infection of the various varieties and strains are given for each year in Tables 1 and 2. In addition to the

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[3] The tests reported in this paper were begun at the Judith Basin Branch Station in the fall of 1926 by R. W. May and continued by B. B. Bayles from 1927 to 1930, and at the North Platte Substation in 1929 by G. F. Sprague.

TABLE 1.—*Annual and average percentage of bunt in winter wheat varieties and selections grown from smutted seed at the Judith Basin Branch Station, Moccasin, Mont., 1927 to 1932.*

Variety or strain	Nursery or selection No.	C. I. No.	Percentage of bunt in 1927	1928	1929	1930	1931	1932	Average for variety	Average for Nebr. No. 60 same years, %	Percentage of Nebr. No. 60
Hussar	—	4843	—	—	0	T	—	2	1	32	3
Turkey x Bearded Minn. No. 48	—	8243	—	—	—	T	0	7	2	42	5
Turkey sel.	—	10016	—	—	—	0	2	3	2	42	5
Cooperatorka	—	8861	—	—	—	T	0	10	3	42	7
Ridit	—	6703	14	—	0	0	—	1	4	53	8
Minturki x Beloglina-Buffum	Nur. No. 160	—	—	2	1	2	1	—	2	24	8
Yogo	—	8033	12	2	3	9	1	3	5	39	13
Rio	—	10061	—	—	0	3	1	11	4	32	13
Wheat-Rye	—	8890	—	—	—	4	9	13	9	42	21
Oro	—	8220	—	—	—	9	13	8	10	42	24
Minturki	—	6155	23	14	0	10	2	9	10	39	26
Turkey sel.	—	10015	—	—	—	—	5	10	8	27	30
Beloglina	—	1543	35	1	5	18	0	27	14	39	36
Minard x Minhardi	—	8888	—	—	—	15	9	33	19	42	45
Minessa	—	6154	22	5	0	27	10	41	18	39	46
Minhardi x Minturki	—	8215	—	—	2	10	21	25	15	32	47
Kanred x Minessa	—	8045	29	9	13	7	15	38	19	39	49
Turkey x Minessa	Nur. No. 54	—	—	8	1	32	19	38	20	30	67
Minturki x Beloglina-Buffum	B. H. 23–4	—	—	—	—	—	15	24	20	27	74
Turkey x Minessa	—	8887	62	29	6	24	21	43	31	39	79
Kanred x Marquis	IX-3	—	—	—	—	46	0	56	34	42	81
Minturki x Kanred	B. H. 22–4	—	—	—	—	—	5	38	22	87	81
Quivira	—	8886	—	—	—	51	0	54	35	42	83
Minard	—	6690	70	12	7	48	10	52	33	39	85
Turkey x Minturki	B. H. 6–1	—	—	—	—	—	11	35	23	27	85
Blackhull	—	6251	—	—	—	61	0	46	36	42	86
Minard x Minhardi	—	8052	—	24	0	40	8	70	28	30	93
Don	—	—	—	—	—	—	1	49	25	27	93
Iowin	—	10017	—	—	—	—	0	49	25	27	93

Ukrainka	—	8859	—	—	—	69	0	—	35	37	95
Kanred	—	5146	89	27	8	53	0	51	38	39	97
Kharkof	—	6938	—	—	6	27	13	79	31	32	97
Newturk sel. 9	—	—	—	—	—	56	0	66	41	42	98
Nebraska No. 60	—	6250	83	21	2	73	0	53	39	—	100
Turkey x Minturki	B. H. 6–2	—	—	—	—	—	30	24	27	27	100
Minard x Minhardi	—	8889	—	—	—	55	19	54	43	42	102
Newturk	—	6935	86	48	1	53	0	50	40	39	103
Minard x Minhardi	—	8218	—	—	5	44	16	65	33	32	103
Kharkof	—	1583	89	18	1	62	0	76	41	39	105
Beloglina sel	—	8884	—	—	—	58	10	73	44	42	105
Kanred sel. 4	—	—	—	—	—	54	3	75	44	42	105
Kharkof	—	1442	—	—	8	67	4	58	34	32	106
Cheyenne	—	8885	—	—	—	52	16	68	45	42	107
Kawvale	—	8180	—	20	14	59	0	74	33	30	110
Beloglina-Buffum	—	5545	88	31	4	59	0	81	44	39	113
Kanred x Beloglina-Buffum	Nur. No. 151	—	—	36	6	34	18	74	34	30	113
Kharkof (Hays No. 2)	—	6686	88	29	8	67	6	64	44	39	113
Karmont	—	6700	92	42	5	62	0	67	45	39	115
Turkey	—	6152	82	32	3	48	41	69	46	39	118
Minhardi x Minturki	—	8034	89	29	18	67	10	62	46	39	118
Turkey	—	1558	90	24	2	68	33	79	49	39	126
Wisconsin No. 21.25	—	10018	—	—	—	77	11	74	54	42	129
Turkey x Minessa	—	11505	—	39	13	37	27	80	39	30	130
Hostianium	—	7660	—	—	—	58	4	55	56	42	133
Lutescens	—	8896	—	—	—	66	28	88	61	42	145
Kanred x Minhardi	—	8040	93	55	11	91	12	88	58	39	148
Russian, Kans. No. 475	—	—	—	—	—	—	8	71	40	27	148
Montana No. 36	—	5549	89	54	11	72	—	68	59	39	151
Tuer	—	7619	—	—	—	—	12	73	43	27	151
Buffum No. 17	—	3330	90	57	23	61	51	87	62	39	159
Minhardi	—	5149	90	73	22	70	50	88	66	39	169
Eureka x Minhardi	—	8036	93	73	19	90	68	86	72	39	185
Kanred x Minhardi	Nur. No. 133	—	—	70	23	74	42	81	58	30	193
Kanred x Minhardi	—	8042	—	72	31	74	27	86	58	30	193
Kanred x Minhardi	—	10000	—	44	26	92	—	90	63	30	210

TABLE 2.—*Annual and average percentage of bunt in winter wheat varieties and selections grown from smutted seed at North Platte, Nebr., 1929 to 1932.*

Variety or strain	State, hybrid, or selection No.	C. I. No.	Percentage of bunt infection in				Average of variety	Average for Nebr. No. 60 same years, %	Percentage of Nebr. No. 60
			1929	1930	1931	1932			
Albit	———	8275	0	0	0	0	0	32	0
Turkey sel	———	10016	–	–	0	0	0	31	0
White Odessa	———	2308	0	–	T	0	T	32	T
Wheat-Rye	———	8890	–	0	T	0	T	32	T
Turkey x Bearded Minn. No. 48	———	8243	–	–	T	0	T	31	T
Martin	———	1092	0	0	0	1	T	32	T
Yogo	———	8033	0	0	0	1	T	32	T
Ridit	———	6703	0	T	0	1	T	32	T
Sherman	———	4430	0	T	0	1	T	32	T
Cooperatorka	———	8861	1	0	1	2	1	32	3
Kanred x Sherman	———	11510	1	2	1	1	1	32	3
Beloglina sel	———	10013	0	1	1	4	2	32	6
Minturki	———	6155	2	3	0	3	2	32	6
Minturki x Beloglina-Buffum	———	10088	1	1	1	4	2	32	6
Oro	———	8220	0	T	1	6	2	32	6
Turkey	———	1558A	–	–	3	1	2	31	6
Minturki x Beloglina-Buffum	19114VI-13	———	5	2	0	–	2	25	8
Hussar	———	4843	9	0	1	0	3	32	9
Rio	———	10061	–	–	3	2	3	31	10
Minturki x Beloglina-Buffum	19114VI-8	———	7	1	0	–	3	25	12
Minturki x Beloglina-Buffum	19114VI-38	———	8	1	1	–	3	25	12
Turkey sel	———	10015	–	–	4	3	4	31	13
Kanred x Sherman	25–2–6–3	———	9	5	T	6	5	32	16
Beloglina sel	1543–83	———	8	4	1	–	4	25	16
Minhardi x Minturki	———	8215	6	6	1	12	6	32	19
Turkey sel	———	1532	–	–	4	7	6	31	19
Beloglina sel	1543–94	———	4	8	2	–	5	25	20
Kanred x Minessa	———	8045	12	5	2	–	6	25	24
Beloglina sel	1543–27	———	8	10	1	–	6	25	24

Minard x Minhardi	———	8052	8	11	3	–	7	25	28
Marquis x Kanred	Ks. 214536	———	8	7	7	–	7	25	28
Kanred x Minturki	———	8046	12	16	0	13	10	32	31
Beloglina	———	1543	24	10	2	9	11	32	34
Stepniatchka	———	8862	17	3	6	–	9	25	36
Minard x Minhardi	———	8888	–	6	8	25	13	32	41
Regal	———	7364	25	15	1	7	14	32	44
Quivira	———	8886	–	9	8	25	14	32	44
Beloglina sel.	1543–29	———	21	8	6	–	12	25	48
Beloglina sel.	1543–13	———	23	10	4	–	12	25	48
P-1066–1 x Burbank	———	10087	–	–	6	26	16	31	52
Turkey x Minessa	———	8887	–	11	16	28	18	32	56
Minard x Minhardi	———	8218	–	–	5	31	18	31	58
Minard	———	6690	31	14	4	–	16	25	64
Turkey	———	6152	34	18	4	28	21	32	66
Smithsonian	———	10022	–	–	5	37	21	31	68
Blackhull	———	6251	36	31	6	15	22	32	69
Kanred x Marquis	———	10009	15	26	12	–	18	25	72
Superhard	———	8054	24	19	12	–	18	25	72
Middleton Smut Resistant	———	———	49	5	1	–	18	25	72
Kanred	———	5146	31	4	18	42	24	32	75
Minard x Minhardi	———	8889	–	11	17	46	25	32	78
Wisconsin 21.25	———	10018	–	–	13	37	25	31	81
Prelude x Kanred	Ks. 263826	———	73	20	5	11	27	32	82
Fulhard	———	8257	40	51	18	0	27	32	82
Tenmarq	———	6936	28	21	16	43	27	32	84
Kharkof	———	6938	28	28	–	–	28	33	85
Kawvale	———	8180	59	23	4	34	30	32	94
Montana No. 36	———	5549	33	25	14	–	24	25	96
Tenmarq sel.	———	10089	–	–	16	43	30	31	97
Nebraska No. 60	———	6250	33	33	8	54	32	32	100
Kanmarq	———	6937	30	19	26	–	25	25	100
Iowin	———	10017	–	–	12	50	31	31	100
Fulcaster	———	6471	45	44	8	44	33	32	103
Beloglina sel.	———	8884	44	26	25	42	34	32	106
Newturk	———	6935	44	34	21	40	35	32	109
Eureka x Minhardi	———	8036	70	17	2	49	35	32	109
Beloglina sel.	1543–53	———	59	23	14	47	36	32	113

TABLE 2.—*Concluded.*

Variety or strain	State, hybrid, or selection No.	C. I. No.	Percentage of bunt infection in 1929	1930	1931	1932	Average of variety	Average for Nebr. No. 60 same years, %	Percentage of Nebr. No. 60
Early Blackhull	—	8856	50	38	38	22	37	32	116
Kanred x Minhardi	—	8038	38	31	19	–	29	25	116
Cheyenne	—	8885	–	35	18	58	37	32	116
Prelude x Kanred	Ks. 255161	—	88	25	7	33	38	32	119
Nebraska No. 30	—	7358	47	29	13	–	30	25	120
Turkey (local)	—	—	58	48	17	33	39	32	122
Kharkof (Hays No. 2)	—	6686	54	49	21	32	39	32	122
Marquis x Kanred	Ks. 441	10008	47	35	10	–	31	25	124
Nebraska No. 6	—	6249	51	21	28	–	33	25	132
Kanred x Minturki	—	10012	82	52	16	23	43	32	134
Kanred x Minturki	6–10–7–15	—	48	42	11	–	34	25	136
P-1066 x Marquis	Ks. 215419	—	78	19	6	–	35	25	140
Kanred x Minhardi	—	8042	66	25	28	59	45	32	141
Harvest Queen	—	6199	52	49	14	72	47	32	147
Beloglina sel.	1543–70	—	88	16	6	–	37	25	148
P-1068 x Bluestem	—	8079	73	26	15	–	38	25	152
Karmont	—	6700	63	61	30	43	49	32	153
Kharkof	—	1442	65	41	25	68	50	32	156
Kanred x Hard Federation	Ks. 255085	—	75	28	16	–	40	25	160
Kanred x Minturki	6–10–7–18	—	68	38	18	–	41	25	164
Minhardi	—	5,149	88	47	20	60	53	32	166
Ukrainka	—	8,859	68	46	15	–	43	25	172
Kanred x Minturki	6–10–14–3	—	65	49	18	–	44	25	176
Kanred x Minhardi	—	8040	61	72	24	72	57	32	178
Kanred x Minhardi	6–10–14–6	—	76	41	23	–	47	25	188
Prelude x Kanred	Ks. 264138	—	93	37	13	–	48	25	192
Kanred x Minturki	6–10–1–3	—	47	51	48	–	49	25	196
Kanred x Hard Federation	Ks. 254634	—	92	34	22	–	49	25	196
Buffum	—	3330	93	41	–	–	67	33	203
Kanred x Hard Federation	Ks. 243518	—	97	47	18	–	54	25	216
Prelude x Kanred	Ks. 263755	—	77	47	39	–	54	25	216

varieties listed in the tables, a large number of hybrid selections were tested for a 2-year period, but data are not included since they showed no resistance. Since all varieties were not grown each year, the average infection in percentage of Nebraska No. 60 for the same years is given for comparison. The variet es are arranged in the tables in the order of their resistance as compared to Nebraska No. 60.

Of special interest to breeders are the rather large number of varieties and strains that appear to be highly resistant to bunt. Twenty-six of the 42 grown at both stations were more resistant than Nebraska No. 60, and 11 averaged not more than 10% of bunted heads at either station. There were 33 varieties at Moccasin and 60 at North Platte that were more resistant than Nebraska No. 60. Many of these are of commercial importance, known to possess agronomic qualities of merit. Minturki, a resistant variety grown commercially in the Great Plains, was exceeded in resistance by 10 varieties at Moccasin and 12 varieties at North Platte.

At North Platte, Albit and Turkey selection (C. I. No. 10016) were the only varieties showing no infection. At Moccasin no variety was entirely free from smut. Ridit, Cooperatorka, and Oro are particularly worthy of mention. Blackhull, Kanred, and certain other strains of Turkey appear to be slightly more resistant than Nebraska No. 60, but the differences are probably not important. Among the newer varieties Turkey selection (C. I. Nos. 10016 and 10015) from Nebraska and Yogo and Rio seem especially to merit attention. Hussar, Martin, and Sherman, the latter two grown at North Platte only, are shown to be highly resistant, thus verifying earlier information concerning these varieties.

The data for 42 varieties and strains grown at both stations are given in Table 3. This table gives the percentage of infection at each station as compared with that of Nebraska No. 60 and the rank was determined on the same basis.

It is apparent that substantially the same results were obtained from each station. This is indicated especially in the last three columns of Table 3. It is further indicated by the correlation between the actual averages secured at both stations, the coefficient being 0.823 ± 0.034. The relative resistance from year to year at each station is also of interest and, therefore, the interannual correlation coefficients have been calculated and are presented in Tables 4 and 5. These interannual coefficients vary from about 0.6 to 0.8 at North Platte and from 0.3 to 0.9 at Moccasin. The percentage of infection was very low at Moccasin in 1929 and 1931 and at North Platte in 1931. As a consequence there were no doubt a considerable number of "escapes" and this is responsible for the rather low coefficients involving those years, especially at Moccasin.

Correlations between years when high degrees of infection were obtained are of special interest. At North Platte, relatively high infection was obtained in 1929 and 1932, indicating favorable conditions for smut in those years. The correlation was 0.740 ± 0.047. At Moccasin the average infection was much the same in 1930 and 1932, and the correlation was 0.870 ± 0.022. These high correlations indicate that the reaction of the selections studied was much the same

TABLE 3.—*Summary of results of comparative bunt infection tests with 42 winter wheat varieties at Moccasin, Mont., and North Platte, Nebr., 1927 to 1932.*

Variety or selection	C. I. No.	Number of years tested		Average percentage of bunt			Average in percentage of Nebr. No. 60 same years			Rank		
		Moccasin	North Platte	Moccasin	North Platte	Both stations	Moccasin	North Platte	Both stations	Moccasin	North Platte	Both stations
Turkey x Bearded Minn. No. 48	8243	3	2	2	0	1	5	0	3	2	1	1
Turkey sel.	10016	3	2	2	0	1	5	0	3	3	2	2
Ridit	6703	4	4	4	0	2	8	0	4	5	3	3
Cooperatorka	8861	3	4	3	1	2	7	3	5	4	6	4
Hussar	4843	4	4	1	3	2	3	9	6	1	9	5
Yogo	8033	6	4	5	0	3	13	0	7	6	4	6
Wheat-Rye	8890	3	3	9	0	5	21	0	11	8	5	7
Rio	10061	4	2	4	3	4	13	10	12	7	10	8
Oro	8220	3	4	10	2	6	24	6	15	9	7	9
Minturki	6155	6	4	10	2	6	26	6	16	10	8	10
Turkey sel.	10015	2	2	8	4	6	30	13	22	11	11	11
Minhardi x Minturki	8215	4	4	15	6	11	47	19	33	14	12	12
Beloglina	1543	6	4	14	11	13	36	34	35	12	15	13
Kanred x Minessa	8045	6	3	19	6	13	49	24	37	15	13	14
Minard x Minhardi	8888	3	3	19	13	16	45	41	43	13	16	15
Minard x Minhardi	8052	5	3	28	7	18	93	28	61	20	14	16
Quivira	8886	3	3	35	14	25	83	44	64	17	17	17
Turkey x Minessa	8887	6	3	31	18	25	79	56	68	16	18	18
Minard	6690	6	3	33	16	25	85	64	75	18	20	19
Blackhull	6251	3	4	36	22	29	86	69	78	19	22	20
Minard x Minhardi	8218	4	2	33	18	26	103	58	81	27	19	21
Kanred	5146	6	4	38	24	31	97	75	86	23	23	22
Minard x Minhardi	8889	3	3	43	25	34	102	78	90	26	24	23
Kharkof	6938	4	2	31	28	30	97	85	91	24	26	24

Turkey	6152	6	4	46	21	34	118	**66**	92	35	21	25
Iowin	10017	2	2	25	31	28	93	100	97	21	29	26
Nebraska No. 60	6250	6	4	39	32	36	100	100	100	25	30	27
Kawvale	8180	5	4	33	30	32	110	94	102	32	27	28
Newturk	6935	6	4	40	35	38	103	109	106	28	32	29
Beloglina sel	8884	3	4	44	34	39	**105**	106	106	29	31	30
Wisconsin No. 21.25	10018	3	2	54	24	40	129	81	109	36	25	31
Cheyenne	8885	3	3	45	37	41	107	116	112	31	34	32
Kharkof (Hays No. 2)	6686	6	4	44	39	42	113	122	118	33	35	33
Montana No. 36	5549	6	3	59	24	42	151	96	124	38	28	34
Kharkof	1442	4	4	34	50	42	106	156	131	30	38	35
Ukrainka	8859	2	2	35	57	46	95	173	134	22	39	36
Karmont	6700	6	4	45	49	47	115	153	134	34	37	37
Eureka x Minhardi	8036	6	4	72	35	54	185	109	147	41	33	38
Kanred x Minhardi	8040	6	4	58	57	58	149	178	164	37	41	39
Kanred x Minhardi	8042	5	4	58	45	52	193	141	167	42	36	40
Minhardi	5149	6	4	66	53	60	169	166	168	40	40	41
Buffum No. 17	3330	6	2	62	67	65	159	203	181	39	42	42

TABLE 4.—*Correlation of percentage of bunt infection of the same varieties grown in different years, North Platte, Nebr.*

	Correlation coefficients between years indicated		
	1930	1931	1932
1929	0.751 ±0.033	0.598±0.049	0.740±0.047
1930	—	0.739±0.033	0.683±0.052
1931	—	—	0.698±0.045

TABLE 5.—*Interannual correlations of percentage of bunt infection of the same varieties grown in different years at Moccasin, Mont.*

	Correlation coefficients between years indicated				
	1928	1929	1930	1931	1932
1927	0.711±0.071	0.409±0.117	0.919±0.022	0.303±0.134	0.893±0.039
1928	—	0.719±0.059	0.732±0.056	0.675±0.068	0.735±0.057
1929	—	—	0.920±0.018	0.598±0.074	0.608±0.070
1930	—	—	—	0.325±0.084	0.870±0.022
1931	—	—	—	—	0.419±0.072

in different years and at both stations. The correlation between the results obtained in 1932 with the 35 selections tested at both stations was 0.889 ± 0.024, indicating that the agreement between stations when relatively high infection is obtained, is as good as that between years at one station.

Taken as a whole and for the varieties included these data seem to afford little or no evidence for the belief that the forms of bunt at the two stations are substationally different or that the results vary from year to year. It is true that the relative infection of certain varieties is somewhat different in some cases; however, it seems more reasonable to attribute this to environment rather than to physiologic forms of bunt.

The results are of particular interest in suggesting that data on bunt reaction for a single year are a fairly reliable criterion of what may be expected in any other year, and for either location, provided good infection of susceptible varieties is secured, and provided no new forms of bunt appear. This is directly in contrast with yield determinations in which the relative yield of varieties is known to fluctuate greatly from year to year. This suggests that bunt resistance tests need be of relatively short duration especially for susceptible varieties, and likewise that the results for any one location in the Great Plains may have a rather wide application.

SELF-INCOMPATIBILITY IN YELLOW SWEET CLOVER, *MELILOTUS OFFICINALIS*[1]

R. A. BRINK[2]

From the standpoint of the methods which may be used in their improvement and the degree of genetic uniformity in varieties which it is possible to attain, self-incompatible species constitute a distinct category of plants. Self-incompatability (self-sterility), the essential feature of which is the relative ineffectiveness of the normally constituted pollen of a plant to develop pollen tubes in the pistil of the same individual, is not an uncommon phenomenon among cultivated plants. Like the rarer conditions, dioecism and dichogamy, it deprives the breeder of the free use of one of his most incisive and widely applied procedures, namely, self-fertilization. The handicap is, indeed, a very considerable one, as the livestock breeder who has no recourse from the complications of biparental systems of mating, can amply testify.

Of the two sweet clovers of recognized agricultural significance, *Melilotus alba* and *M. officinalis*, the latter species, whose status in this respect has been in doubt for many years, is now shown to be self-incompatible. The fact is of some moment, for it adds to the difficulties of the breeder seeking to overcome those features which at present more or less seriously limit the usefulness of the plant for hay and pasture.

The sweet clovers have become naturalized over a remarkably wide area in North America, a fact which testifies to their general adaptability for cultivation under diverse conditions of climate and soil. The plants are especially notable for their aggressiveness, abundant seed production, gross feeding powers for mineral nutrients, nitrogen-gathering capacity, and ability to exploit the moisture supply of the soil. On the other hand, both species are coarse in texture and so bitter that they are relatively unpalatable to livestock. It is generally admitted that these latter characteristics offset to a large extent those which commend the plant for forage purposes. In species so recently brought under cultivation as the sweet clovers, however, one must distinguish between present and potential values. As farm crops go, the sweet clovers have had but the briefest history; and it is only within the last decade that they have been accorded serious attention by plant breeders. Even within this short period of time, however, significant heritable variability in the features which now restrict the agricultural usefulness of the plants has been established by Kirk (5)[3] and others. These discoveries afford grounds for thinking that a continuation of the systematic search being made for major variations of agronomic value and the incorporating of them into domesticated varieties eventually will raise

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[2] Professor of Genetics.

[3] Numbers in parenthesis refer to "Literature Cited," p. 312.

the sweet clovers to important rank as forage crops. A primary requisite in gaining this objective is a knowledge of the reproductive processes in their relations to breeding technic. The present paper, dealing with the common yellow-flowered species, is a contribution to that end.

In 1883, Müller (3) pointed out that in *Melilotus officinalis* the stigma projects so far beyond the anthers that self-pollination is rendered unlikely. He observed that it is more extreme in this respect than is *Trifolium repens*. In this species cross fertilization by insects was believed to occur regularly since the stigma extends slightly beyond the anthers and, therefore, comes first in contact with the ventral surface of the insect after the latter thrusts its head between the standard and the alae. Darwin (1) has been quoted by different writers, including Knuth (10), as authority for the statement that *M. officinalis* is self-sterile. A careful reading of the original account reveals, however, that while Darwin showed that an unprotected plant visited by bees produced at least 30 times more seed than one protected by a cage, he recognized that such a result might have followed from either of two entirely distinct causes, namely, lack of pollination of the protected flowers or non-functioning of the pollen after it was brought in contact with the stigma. It was not essential to Darwin's purpose to determine which of these causes was operative in the case in question.

Kirchner (4) obtained 74 pods with 71 seeds from five open-pollinated inflorescences; 11 isolated inflorescences on another plant yielded only 11 pods with one seed each and five empty pods. A subsequent experiment involving 622 flowers covered with a net gave 222 pods. On another plant the isolated inflorescence died. In his summary table, Kirchner gives 97% "Samenansatz bei spontaner Selbstbestäubung" for *M. officinalis*. This value is obviously not in accord with Kirchner's detailed findings as presented earlier in his paper. One gathers from his account, however, that Kirchner thinks the plant is self-fertile. Its failure to set seed regularly under protection in his and in Darwin's experiments is attributed to sensitiveness of the plant to enclosure in a net.

Kirk (6) found that *M. officinalis* sets seed much more abundantly in the open than when protected from insect visitation by cotton cages. Six plants thus guarded during the entire flowering period formed on the average only 2.6 pods per raceme. Unprotected inflorescences on the same plants, on the other hand, gave an average of 63.9 pods each. Working with several races of yellow sweet clover over a period of years, Kirk and Stevenson (8) found no indication of spontaneous self-fertilization except in the variety Redfield Yellow. The latter form was found to set seed more or less freely in the absence of pollen-bearing insects, a fact which the present writer can confirm. It is very doubtful, however, whether Redfield Yellow belongs to *M. officinalis*. In the winter of 1931–32 the author obtained only 1 seed in 129 attempts to cross it with various representatives of the latter species, and this single seed proved on testing to be an accidental self. Numerous crosses, made at the same time and in the same manner, between common yellow sweet clover plants were all fruitful, averaging about one pod for each three flowers castrated and pollinated.

Kirk and Stevenson (8) made the significant observation that in Albotrea, a variety of common yellow sweet clover, pollen is in contact with the stigmas in most flowers even before the petals have expanded; nevertheless, little seed is formed. Large increases in seed yield were obtained by rubbing the stigma of castrated flowers with the flat end of a toothpick before applying the pollen. Similar treatment with a camel's hair brush was less effective. The authors conclude that scarification with a toothpick tends to make the stigma receptive. The work of Kirk and Stevenson (8, 9) demonstrates clearly that in yellow sweet clover plants which are protected from insects failure to set seed is not due solely to lack of pollination. A barrier to self-fertilization of some other sort likewise exists. They suggest that the essential factor is "a characteristic of the stigma which makes it unreceptive."

The writer's experiments were carried out mainly on a group of four plants dug from the field in the fall of their seedling year and brought into flower in the greenhouse during the winter of 1932–33. Aside from numerous thrips and a few aphids, neither of which, however, appear to transport pollen, the plants were not visited by insects. The four individuals used were hybrids between sibs from a family of fine-stemmed yellow plants derived by self-pollination of a single individual of this type and selected plants from stocks designated Common Yellow, Albotrea, Suaveolens, and Daghestan, respectively. While differing in numerous minor details all the hybrids were tall and coarse-stemmed and fell within the range of variation seen in *M. officinalis*.

Only one pod was set by the 416 flowers which were not treated in any way. This is a yield of 0.24% and agrees, in general, with the earlier findings discussed above.

In order to test the conclusions of Kirk and Stevenson (8) that irritation of the stigma increases the set of seed after self-pollination the following experiment was arranged. Toothpicks were prepared by gluing to their tips narrow strips of paper differing in degree of roughness. What was termed No. 1 paper for the purposes of the test was a coated product, very smooth and glossy. No. 2 paper was a common type of letter paper with a moderately smooth surface. No. 3 paper, on the other hand, was rough, being somewhat coarser than ordinary newsprint. In addition a set of toothpicks was tipped with No. 00 emery cloth, the abrasiveness of which had been moderated by drawing the cloth several times over an iron rod. An unmodified set of toothpicks completed the equipment.

Kirk and Stevenson (8) rubbed the stigmas with plain toothpicks and with camel's hair brushes before pollination, the pollen being applied subsequently by means which they do not specify. In the present experiments the pollen was gathered upon the variously equipped toothpicks and applied directly by passing the respective pollen-laden tips several times across the stigmas. The results of selfing by these means are summarized in Table 1.

TABLE 1.—*Effect of applying pollen from surfaces differing in degree of roughness.*

Pollinating surface	No. of flowers pollinated	No. of pods formed	Percentage of flowers setting pods
Plain toothpick	221	40	18.1
No. 1 paper	231	41	17.7
No. 2 paper	196	45	22.9
No. 3 paper	326	71	21.8
No. 00 emery	527	120	22.8

There does not appear to be any real difference between the percentage of flowers setting pods following the different modes of applying the pollen.

A clue to the basic factor involved in the successful pollination of yellow sweet clover was afforded by the results of crosses between different plants. Without castration a series of pollinations were made between pairs of plants by working three flowers on each individual alternately. In this way the emery-tipped toothpicks which were used carried pollen from two individuals and presumably deposited a portion of the mixture on each stigma. Of the 448 flowers treated in this way on seven pairs of plants 322 set pods, a percentage of 71.9. This is over three times the proportion of pods formed on self-pollinating the same individuals with the same instrument. The inference seemed clear that pollen from another rather than from the same plant is more effective in promoting seed formation.

In order to test this possibility in a more precise way a number of flowers were castrated, using the suction method described by Kirk (7), and subsequently treated as follows. Some of the castrated flowers on each of the five plants used were not pollinated. These served as the checks. Another group was pollinated using pollen from the same respective individuals. The remaining flowers were cross-pollinated. The results are given in summary form in Table 2.

TABLE 2.—*Relative numbers of pods set on self- and cross-pollination of castrated flowers.*

Treatment	No. of flowers	No. of pods formed	Percentage set
Not pollinated	138	7	5.1
Selfed	165	27	16.4
Crossed	187	88	47.1

While the set is not high in either case, due in part possibly to frequent injury of the pistil in castrating, the crossed flowers set proportionately about three times as many pods as the selfed flowers. There can be little doubt as to the statistical significance of this difference. It may be remarked that of the seven pods formed among the checks, six occurred together on one inflorescence and may have resulted from cross-pollinating these flowers by mistake. Only one pod formed on the remaining six inflorescences in which the flowers were castrated and not pollinated.

East (2) has shown that with certain self-sterile species of Nicotiana amounts of seed approaching the full complement may be obtained by self-pollinating the flowers in the bud stage. This method was tried with yellow sweet clover with but little success. Of 780 flowers selfed with the aid of a toothpick carrying an abundance of pollen collected from mature flowers at as early a stage as the buds could be conveniently manipulated 127 formed pods. This is a set of 16.3%, a value somewhat lower than the average from selfs made after the petals were fully expanded.

In yellow sweet clover plants in which the disparity in length of stamens and style is not very large, self-pollination may be accomplished by gently rolling the flowers between one's thumb and fingers. The writer obtained a 15.0% set in this way with 459 flowers on the four plants under test. Rolling is a much more rapid means of pollinating than manipulating each flower with a toothpick. Unfortunately, however, it does not work at all on plants in which the style projects a considerable distance beyond the anthers, and individuals of this type are fairly common.

While little exact evidence is at hand in support of the view, it appears probable that different yellow sweet clover plants vary in their norms for self-incompatibility. During the summer of 1932, for example, a single fine-stemmed yellow sweet clover was discovered at Madison which was isolated by removing the few other common yellow plants in the vicinity. Bees visited the fine-stemmed individual freely and it set about 4,000 seeds. The fine-stemmed condition is a recessive, and of the approximately 2,000 offspring from the original plant which were grown during the past summer less than 1% were of the tall coarse type. Evidently self-fertilization was more or less readily accomplished in this case. The writer, likewise, found one plant in the greenhouse during the past winter which set seed readily on selfing. Other individuals under the same circumstances, however, gave very low yields. The degree of self-incompatibility is known to vary rather widely in other species which have been intensively studied so it is not surprising to find that yellow sweet clover exhibits this behavior. To what extent the fact may be taken advantage of in breeding is not known.

The immediate cause of self-incompatibility in yellow sweet clover is a retarded development of the pollen tubes in the style after selfing. The author is indebted to Dr. D. C. Cooper for making numerous histological preparations of styles at various intervals of time up to 24 hours after selfing and crossing. The procedure adopted was to remove as much of the cortex of the style as possible by teasing it off with a needle and fixing the remaining tissue in Karpechenko's modification of Navaschin's fluid. While various stains were used, the clearest differentiation of the pollen tubes in smear preparations was obtained with the iodine-gentian violet stain.

After cross-pollination the pollen germinates promptly, the tubes enter the style readily, and are found in large numbers in the vicinity of the ovary after 24 hours. The behavior after selfing is strikingly different. Fewer pollen grains germinate, and from only a part of these do pollen tubes become established in the style. The remaining tubes, which remain relatively very short, curl among the papillae of the stigma. Twenty-four hours after self-pollination comparatively few of the pollen tubes within the style have grown beyond the stigmatic region. Occasionally, however, a tube may be found to have progressed half-way or more down the style. Presumably it is a few of these latter tubes that eventually penetrate to the embryo sac, making sporadic self-fertilization possible.

SUMMARY

1. Common yellow sweet clover, *Melilotus officinalis*, is shown to be self-incompatible. Under greenhouse conditions about three times as many flowers formed pods after cross-pollination as after self-pollination.
2. The immediate cause of the self-incompatibility is a reduced rate of germination of the pollen of a plant on its own stigma, failure of many of the tubes formed to become established in the style, and the slow growth of those which do penetrate the pistil. Following cross-pollination the pollen grains germinate freely, and the tubes are found in large numbers at the base of the style after 24 hours.
3. While little evidence is available on the point, individual yellow sweet clover plants appear to vary significantly in their norms for self-incompatability. Ordinarily, few seed are obtained on selfing, but the writer has observed two individuals, one isolated in the field and the other grown in a greenhouse, which set seed rather abundantly with their own pollen.

LITERATURE CITED

1. Darwin, Chas. The effects of cross and self fertilisation in the vegetable kingdom. New York. 1885.
2. East, E. M. Self-sterility. Bibliographia Genetica, 5:331–370. 1929.
3. Müller, H. The fertilisation of flowers. London: Trans. by D'Arcy W. Thompson. 1883.
4. Kirchner, O. Über die Wirkung der Selbstbestäubung bei den Papilionaceen. Naturw. Ztschr. Land. u. Forstw. Jahrg., 3 (1): 1–16; (2): 49–64; (3):97–111. 1905.
5. Kirk, L. E. Aberrant forms of Arctic sweet clover. Sci. Agr., 5:113–116. 1924.
6. ———. Self-pollination of sweet clover. Sci. Agr., 6:109–112. 1925.
7. ———. Abnormal seed development in sweet clover species crosses. A new technique for emasculating sweet clover flowers. Sci. Agr., 10:321–327. 1930.
8. ———, and Stevenson, T. M. Factors which influence spontaneous self-fertilization in sweet clover (Melilotus). Can. Jour. Res., 5:313–326. 1931.
9. ———, ———. Spontaneous self-fertilization in relation to seed production in sweet clover (Melilotus) Can. Jour. Res., 5:660–664. 1931.
10. Knuth, Paul. Handbook of flower pollination, based on Herman Müller's work upon The fertilisation of flowers by insects, Trans. by J. R. A. Davis. Oxford. 1906–08.

EFFECT OF FERTILIZERS ON THE YIELD OF COTTON AND ON THE CONTROL OF THE ROOT-ROT DISEASE OF COTTON ON THE BLACKLAND PRAIRIE SOILS OF TEXAS[1]

E. B. REYNOLDS AND H. E. REA[2]

The soils of the Blackland Prairie in Texas, consisting mostly of the Houston black clay and Houston clay, are the well-known "black waxy" soils of the state. These are extensive and important agricultural soils, occupying an area of about 11,000,000 acres. The Houston soils are naturally productive. When first put into cultivation about 1865, it was commonly believed that the soils were practically inexhaustible. It is generally known, however, that they are not so productive now as they were when first brought into cultivation. The average yield of cotton in the region has declined from 226 pounds per acre for the 10-year period 1866–75 to 135 pounds per acre for the 10 years 1916–25. This decline in productiveness has been ascribed to various causes, including depletion of plant food, soil erosion, and insects and diseases which are favored by the almost continuous growing of cotton in the region.

The cotton root-rot disease, caused by the fungus *Phymatotrichum omnivorum* (Shear) Duggar, is the most destructive disease of cotton and no doubt has been one of the factors in reducing the yield. The annual losses from this disease have been estimated at 10 to 15% of the total cotton crop in Texas.[3]

Although the average yield of cotton in the Blackland Prairie has declined sharply since 1870, the results obtained at Texas Substation No. 5, Temple, have shown that proper rotations will help maintain the yield of cotton.[4] Fertilizers had been tried in a small way by the Experiment Station and by farmers in the region, but in general the use of fertilizers was not profitable.

Since the yield of cotton had declined to such a low level and since the root-rot disease had become so prevalent and destructive, it became imperative to try to develop methods or practices that could be used profitably in increasing the yield of cotton under root-rot conditions. Although fertilizers had not given consistently good results, it was thought that a large number of cooperative experiments with fertilizers with farmers in the region would give some valuable information on the use of fertilizers.

Accordingly, cooperative experiments with fertilizers were begun in 1930 with the view of increasing the yield of cotton by (1) hastening maturity, (2) evading or controlling root-rot, or (3) by a combination of both. These cooperative experiments are a part of the agronomic phase of more comprehensive investigations on the root-rot disease of cotton being conducted by the Texas Agricultural Experiment Station. It is the purpose of this paper to report the results of these cooperative experiments in 1930, 1931, and 1932.

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[2] Chief, Division of Agronomy, and Agronomist, respectively.

[3] TAUBENHAUS, J. J., and EZEKIEL, W. N. Cotton root-rot and its control. Tex. Agr. Exp. Sta. Bul. 423. 1931.

[4] REYNOLDS, E. B., and KILLOUGH, D. T. Crop rotation in the Blackland region of central Texas. Tex. Agr. Exp. Sta. Bul. 365. 1927.

METHODS

These cooperative experiments were conducted with farmers in Bell County which is located near the center of the Blackland Prairie Belt of Texas. The results obtained should be applicable in a general way to other sections of the region.

FERTILIZER TREATMENTS USED

Three fertilizer treatments, 4–8–4, 4–8–0, and 4–0–0, were used at the rate of 400 pounds per acre. Preliminary work with fertilizers at the Experiment Station at Temple indicated that the 4–8–4 analysis contained a suitable ratio of nitrogen, phosphoric acid, and potash. For this reason it was used as the basic treatment in the work. The 6–12–0 analysis was added in 1932. The treatments were carried in triplicate on plats 0.01 acre in size. The fertilizers were made up from nitrate of soda, superphosphate, and muriate of potash.

METHOD OF APPLYING FERTILIZERS

The fertilizers were applied by hand in freshly opened furrows on lister beds prepared several weeks before application of the fertilizer. The fertilizer was covered immediately by forming ridges or beds on the furrow. The unfertilized plats were treated in the same manner, except no fertilizer was used. Cotton was planted on these ridges about 2 weeks later, the seed being placed about 1½ to 2 inches above the fertilizer.

SOIL TYPES USED

Most of the work was conducted on Houston black clay and Houston clay, although several fields in the eastern edge of the Grand Prairie were on San Saba clay which is a limestone soil having characteristics very similar to those of Houston black clay. Of the 85 experiments conducted, 39 were located on Houston black clay, 20 on Houston clay, and 26 on San Saba clay. Only fields that were heavily infested with root-rot were used. New locations were selected each year and in no case had fertilizer been used previously on the soil according to statements of the cooperators. The soils used occurred on smoothly situated locations and were representative fields of the types under consideration.

EXPERIMENTAL RESULTS

EFFECT OF FERTILIZERS ON YIELD OF COTTON

Significant increases in yield of cotton were obtained from some of the fertilizers, especially those which contained phosphoric acid, although the increases, as a rule, were not large enough to be profitable.

Application of fertilizers increased the yield of cotton in a fairly high percentage of tests conducted on the three types of soil used. Of the 39 tests with the 4–8–4 fertilizer on the Houston black clay, 32, or 82.1%, showed some response to applications of fertilizers. In 7 of the 39 tests, no increases in yield were obtained; in 14 tests increases of 1 to 25 pounds of lint were obtained; in 7 tests increases of 26 to 50 pounds were obtained; and in 11 tests increases of 51 pounds or more were obtained (Table 1). In the 20 tests with the 4–8–4 fertilizer on Houston clay, 17 tests, or 85%, produced larger yields than the unfertilized soil. Of these 20 tests, 3 showed no response to fertilizers; 9 tests resulted in increases of 1 to 25 pounds per acre; 6 tests, in increases of 25 to 50 pounds; and 2 tests, in increases of 51 pounds or more per acre. Similar data on the other treatments used on the three soil types also are given in Table 1.

TABLE 1.—*Distribution of increases in yield of lint in pounds per acre produced by fertilizers, arranged according to size of increases.*

Fertilizers used	Number of tests conducted	Number of tests showing				Percentage of tests showing increase in yield
		No increases in yield	Increases of 1 to 25 lbs.	Increases of 26 to 50 lbs.	Increases of 51 to 75 lbs.*	
		Houston Black Clay				
4–8–4.....	39	7	14	7	11	82.1
4–8–0.....	39	5	15	8	11	87.2
6–12–0....	7	1	4	0	2	85.7
4–0–0.....	39	12	14	10	3	69.2
		Houston Clay				
4–8–4.....	20	3	9	6	2	85.0
4–8–0.....	20	4	6	9	1	80.0
6–12–0....	6	0	3	3	0	100.0
4–0–0.....	20	6	10	4	0	70.0
		San Saba Clay				
4–8–4.....	26	1	13	8	4	96.2
4–8–0.....	26	3	10	10	3	88.5
6–12–0....	8	1	2	4	1	87.5
4–0–0.....	26	8	11	6	1	69.2

*In one test on the Houston black clay in 1931 the 4–8–4 fertilizer produced an increase of 129 pounds of lint per acre and the 4–8–0 fertilizer 130 pounds.

Phosphoric acid produced larger increases in yield than either nitrogen or potash on the three soils used, as may be seen by comparing the yields obtained from the 4–8–4, 4–8–0, and 4–0–0 fertilizers (Table 2). On the Houston black clay, for example, the 4–8–0 fertilizer made an average increase of 29 pounds of lint per acre, or 18 pounds more than the 4–0–0 fertilizer. This difference of 18 pounds is ascribed to the effect of the phosphoric acid in the 4–8–0 fertilizer. Similar results were obtained on the Houston clay and San Saba clay.

The use of nitrogen alone increased the yield of cotton 6.4% on the Houston black clay, 5.1% on the Houston clay, and 6.3% on the San Saba clay (Table 2).

TABLE 2.—*Yield per acre of cotton (lint) in cooperative fertilizer experiments on soils in the Blackland Prairie of Texas.*

Fertilizers used	Lbs. of lint				Average increase produced by fertilizers	
	1930	1931	1932	Average	Lbs.	%
			Houston Black Clay			
None	163	215	135	171	—	—
4-8-4	179	259	169	202	31	18.1
4-8-0	181	263	157	200	29	17.0
6-12-0	—	—	160	—	—	—
4-0-0	171	231	144	182	11	6.4
			Houston Clay			
None	150	160	99	136	—	—
4-8-4	161	184	121	155	19	14.0
4-8-0	153	188	121	154	18	13.2
6-12-0	—	—	131	—	—	—
4-0-0	151	172	106	143	7	5.1
			San Saba Clay			
None	153	161	111	142	—	—
4-8-4	176	198	140	171	29	20.4
4-8-0	169	194	141	168	26	18.3
6-12-0	—	—	141	—	—	—
4-0-0	158	178	118	151	9	6.3

Potash was not very effective on either of the three soils used.

The complete fertilizer, the 4-8-4 analysis, made the highest average yield on each of the three soils, resulting in an average increase of 18.1% on the Houston black clay, 14.0% on the Houston clay, and 20.4% on the San Saba clay.

EFFECT OF FERTILIZER ON ROOT-ROT

As mentioned previously, the fertilizer tests were located on soils that were severely and uniformly infested with root-rot so that an accurate test of the effect of fertilizers on the control of the disease could be made. The several fertilizer treatments used had no appreciable effect on the amount of root-rot or on the time the disease attacked the cotton plants on the three soils during the 3 years (Table 3). There were, of course, some slight differences in the percentages of root-rot found on the plats among the several treatments, but the differences were small and inconsistent. It should be kept in mind that these results were obtained where the fertilizers were applied to new areas each year and not to the same areas consecutively for 3 years. It is conceivable that the application of large amounts of fertilizers to the same land every year over a period of years might have a tendency to reduce the infestation of root-rot. However, in soil fertility studies in a rotation of cotton, corn, and oats at the Experiment Station, Temple, Texas, the use of various kinds and rates of application of fertilizers, ranging from 200 to 800 pounds per acre, on Houston black clay for 4 consecutive years, did not reduce the amount of root-rot, although the average yield of cotton was increased 23 to 27.8% by the best fertilizer treatments.[5] These results indicate that it would not be practicable in farm practice to try to control the root-rot disease by the use of fertilizers on the soils under consideration.

TABLE 3.—*Percentage of root-rot on soils which received different fertilizer treatments.*

Fertilizers used	1930	1931	1932	Average
Houston Black Clay				
None	17.0	23.9	54.9	31.9
4-8-4	18.9	22.7	67.2	36.3
4-8-0	17.4	26.0	58.1	33.8
6-12-0	—	—	55.7	—
4-0-0	15.3	25.7	48.3	29.8
Houston Clay				
None	22.8	34.9	33.0	30.2
4-8-4	22.6	35.6	39.8	32.7
4-8-0	23.2	37.0	30.4	30.2
6-12-0	—	—	39.1	—
4-0-0	19.3	38.5	26.4	28.1
San Saba Clay				
None	27.8	75.6	41.9	48.4
4-8-4	29.1	73.1	43.6	48.6
4-8-0	31.6	73.1	43.3	49.3
6-12-0	—	—	39.9	—
4-0-0	27.1	70.4	42.0	46.5

DISCUSSION OF RESULTS

The fertilizer treatments, especially those which contained phosphoric acid, produced significant increases in the yield of cotton. With the prevailing low price of cotton, however, the fertilizers did not return a profit. In fertilizer practice, the placement of the fertilizer material influences the yield of the crop. In this work, as mentioned previously, the fertilizer was applied below the seed because at the time the work was started suitable machines for applying fertilizers were not available. Studies on the placement of fertilizers for cotton in Texas and elsewhere have shown that applying the fertilizer at the side of the seed and below the level of the seed has given best results. The matter of placement of fertilizers conceivably may be, and probably is, of considerable importance on the calcareous soils used in this work on account of their strong fixing power for phosphoric acid. This phase of the matter needs to be studied further before drawing definite conclusions regarding the feasibility of using fertilizers on the soils of the Blackland Prairie of Texas.

The fertilizers used apparently had no appreciable effect on the amount of root-rot present.

SUMMARY

Eighty-five cooperative fertilizer experiments on cotton were conducted with farmers on the soils in the Blackland Prairie of Texas in

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[5] REYNOLDS, E. B., *et al.* Fertilizer experiments with cotton. Tex. Agr. Exp Bul. 469. 1932. Data on root-rot were obtained, but so far have not been published.

1930, 1931, and 1932, to determine the effect of fertilizers on the yield of cotton and on the control of the root-rot disease of cotton.

In these experiments the 4-8-4, 4-8-0, and 6-12-0 fertilizers produced significant increases in yield of cotton, but the increases were not profitable. The fertilizer treatments had no effect on the root-rot disease. These results indicate that on the soils studied the use of fertilizers is not a promising means of reducing or evading the losses caused by the disease.

HETEROSIS OR HYBRID VIGOR IN OATS[1]

F. A. Coffman and L. L. Davis[2]

The beneficial effects of increased vigor which often accrue from crossing unrelated animals or plants have been recognized for centuries, yet investigations of heterosis in the cereal crops have been confined almost exclusively to corn. Because of the difficulty of crossing oats there is little published information on heterosis in this crop. Jamieson,[3] Dietz,[4] Coffman and Wiebe,[5] and Coffman[6] have presented data on heterosis in oats. Jamieson's plants probably were not hybrids, consequently his data are of doubtful value. Dietz's report of increases up to 900% probably indicates the influence of unexplained factors. This paper presents additional data on the characters discussed by Coffman and Wiebe and by Coffman and also on (1) size of crossed seeds, (2) size of F_1 plants, (3) seed vigor of F_1 plants as measured by germination, and (4) heterosis in different plant parts.

Differences of opinion exist as to what constitutes evidence of heterosis. Some consider all increases in the F_1 above the parental mean as evidence of heterosis, whereas others limit it to those increases above the larger of the two parents. The writers, not presenting arguments for or against either view because of space limitations, are of the latter group.

SIZE OF CROSSED OAT SEEDS

Frequently, increased seed weight is an immediate effect of hybridization. Such an increase in seed size usually is attributed to double fertilization. Since it has been observed in several of the cereals, it logically might be expected in oats although apparently it has not previously been reported. Data are presented in Table 1. In de-

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[1] Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Idaho Agricultural Experiment Station. Received for publication June 9, 1933.

[2] Associate Agronomist in Oat Investigations and Assistant Agronomist, formerly in charge of cereal experiments at Aberdeen, Idaho, respectively.

[3] Jamieson, T. Natural cross-fertilization of oats and change of seed. Proc. Agr. Res. Assoc. (Scotland), 1897:31-50; 1898:7-30; 1899:6-19. 1897-99.

[4] Dietz, S. M. Inheritance of resistance in oats to *Puccinia graminis avenae*. Jour. Agr. Res., 37:1-23. 1928.

[5] Coffman, F. A., and Wiebe, G. A. Hybrid vigor in oats. Jour. Amer. Soc. Agron., 22:848-860. 1930.

[6] ——————. Heterosis: Specific not general in nature. Science, 77:114-115. 1933.

TABLE 1.—*Comparative weight in grams of crossed seed of the female parents, of the resulting F_1 seed and groats, and deviation from the larger parent strains.*

Crosses	Comparison of crossed seed and parent*				Weight of seeds and groats of F_1 hybrid† and deviation from the larger parent			
	Mother parent, av. wt. in grams	Hybrid, av. wt. in grams	Deviation from parent		F_1 hybrid, av. wt. grams		Deviation of hybrid from larger parent, av.wt., grams	
			Weight, grams	%	Seed	Groat	Seed	Groat
Nortex x Victoria....	0.0461	0.0397‡	—0.0064	—13.9	0.0396	0.0279	+0.0032	+0.0022
Burt sel. x Victoria..	0.0317	0.0214‡	—0.0097	—32.5	0.0289	0.0203	—0.0055	—0.0041
Schoolmam x Gopher	0.0318	0.0308	—0.0010	— 3.1	0.0247	0.0173	—0.0013	—0.0013
Kanota x Victoria..	0.0420	0.0446	+0.0026	+10.6	0.0370	0.0263	+0.0038	+0.0025
Glen Innis x Victoria.	0.0420	0.0390	—0.0030	— 7.1	0.0384	0.0279	—0.0009	—0.0014

*Grown in greenhouse. †Grown under irrigation. ‡Unusually shriveled.

termining seed weights no attempt was made to remove the glumes from the groats.

Because of the mechanical manipulations necessary in the artificial crossing of oats, injury to the floral parts and consequent reduction in seed size commonly occur. However, in one cross, data for which are given in Table 1, an increase in seed size was observed and the seeds borne on the F_1 plants resulting therefrom were larger on an average than those borne by either parent strain. This indicates that immediate increase in seed size probably results from crossing in at least some oat combinations, just as it does in corn and wheat.

INCREASED SIZE OF F_1 PLANT PARTS

A study of the F_1 generation was conducted under irrigated conditions at Aberdeen, Idaho, in 1930. The F_1 plants were spaced at 1-foot intervals in rows 5 feet long and 1 foot apart. The hybrids were grown in rows between the parent plant rows, on the one side the pollen parent and on the other the ovary parent similarly spaced. Where for any reason there were blanks in the row the space was occupied by a plant of the Richland variety. The characters studied in the F_1 were plant height, length of main panicle, number of culms, total weight of plant, weight of straw and grain, proportion of grain to straw, average weight of individual kernel and of groat, and proportion of groat to total kernel weight and to total plant weight.

The following crosses were studied:

Cross No.	Varieties crossed	No. of crossed plants
X 3012	Nortex x Victoria	3
X 3014	Richland sel. 52 x C. I. No. 2461[7]	2
X 3016	Trojan (Burt sel.)[8] C. I. No. 2491 x Victoria	3
X 3022	Schoolmam x Gopher	3
X 3024	Kanota x Victoria	4
X 3032	Glen Innis x Victoria	4
X S1102	Richland x Sunrise	3
X S1107	C. I. No. 2460 x Iogold	3

Limited space necessitates omitting data on range in size in hybrids and parents. However, comparison shows a similar variation in both. Generally, size characters vary less than weights (total plant, grain, and straw) because weights represent the end result of size variations.

MEASUREMENTS OF HYBRIDS AND PARENTS

Hybridization usually suggests increase in size. In Fig. 1 are compared the physical measurements of hybrid and parent oat plants. In plant height, only one hybrid exceeded its taller parent. The hybrid Richland x Sunrise was nearly 12.5% taller than its taller parent.

In only one of eight crosses, Trojan (Burt sel.) x Victoria, was panicle length of the F_1 greater than that of the larger parent.

Often the number of culms in oat plants is greater in the parent than in its hybrids. An increased number of culms was observed in three of the four hybrids of which Victoria, a heavy tillering variety, was a parent. No other varieties gave such results in their crosses.

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[7] C. I. No. denotes accession number of Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

[8] Selection named Trojan since paper was written.

WEIGHT OF HYBRIDS AND PARENTS

In Fig. 2 are presented data on total plant, straw, and grain weights and ratio of grain to total weight of F_1 hybrids and parents.

The average total weight of plant, straw, and grain of the hybrids exceeded the average of their respective parents in all eight crosses, the larger parent in total plant and grain weight in each of two crosses, and the straw weight of four crosses.

In five of eight crosses the grain-straw ratio was higher in the hybrids than in their parents, which indicates that the hybrid has an increased functional efficiency. The hybrid C. I. No. 2460 x Iogold exceeded its larger parent in all comparisons.

COMPARATIVE WEIGHTS AND PERCENTAGES OF KERNEL AND GROAT IN F_1 HYBRIDS AND PARENTS

In Fig. 3 are compared the weights, in hybrids and parents, of individual kernels and groats, the proportion of groat to total kernel weight, and the proportion of groat to total plant weight.

In seven of eight F_1 crosses the average size of the individual kernel and groat equalled or exceeded that of the mean of their parents.

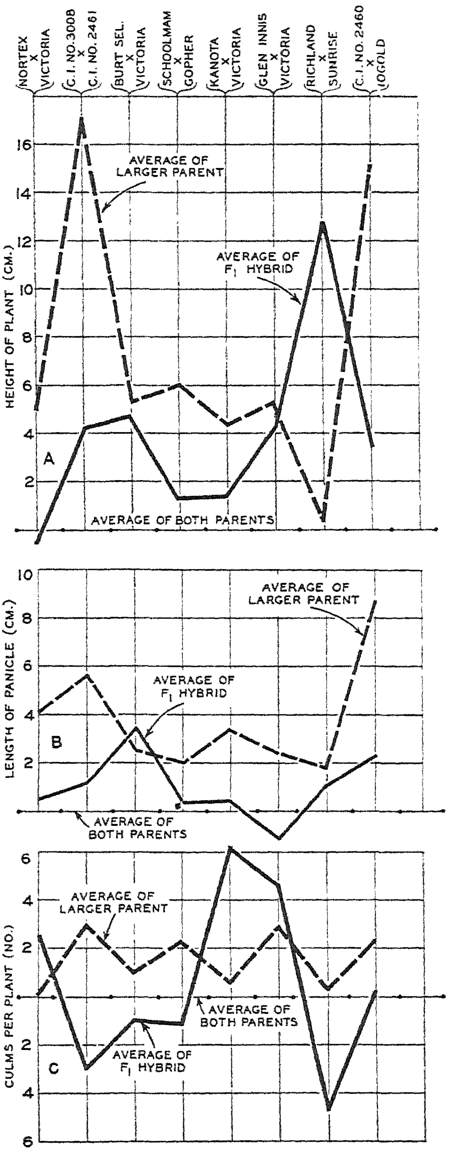

FIG. 1.—Comparison of F_1 hybrid with its larger parent and with the average of both parents in height of plant (A), length of panicle (B), and culms per plant (C).

In kernel size, the hybrids exceeded their larger parents in three of eight crosses and in groat size in two of eight crosses.

In seven of eight crosses the groat yield of the hybrids exceeded

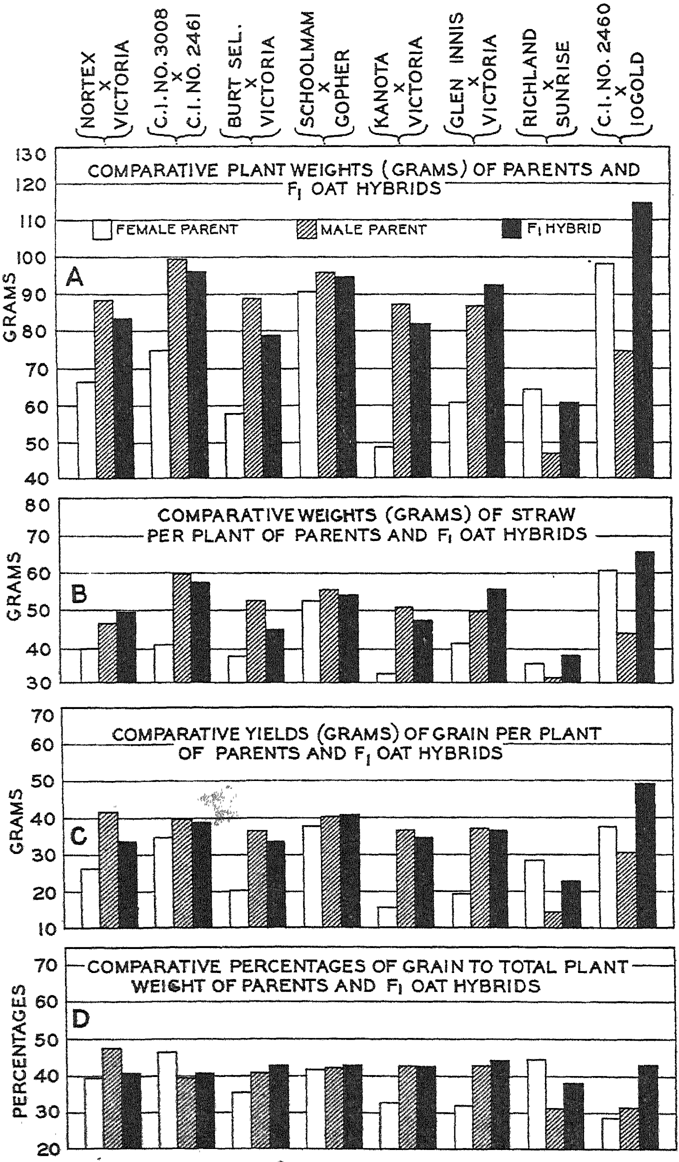

FIG. 7.—Comparison of F_1 hybrid with its parents in total plant weight (A), total weight of straw (B), total yield of grain per plant (C), and comparative percentages of grain to total weight of plant (D).

that of the mean of their parents and in three crosses that of the higher yielding parent. Increased weight of glume and of groat usually was apparent in the hybrids, yet in seven of eight crosses the ratio of

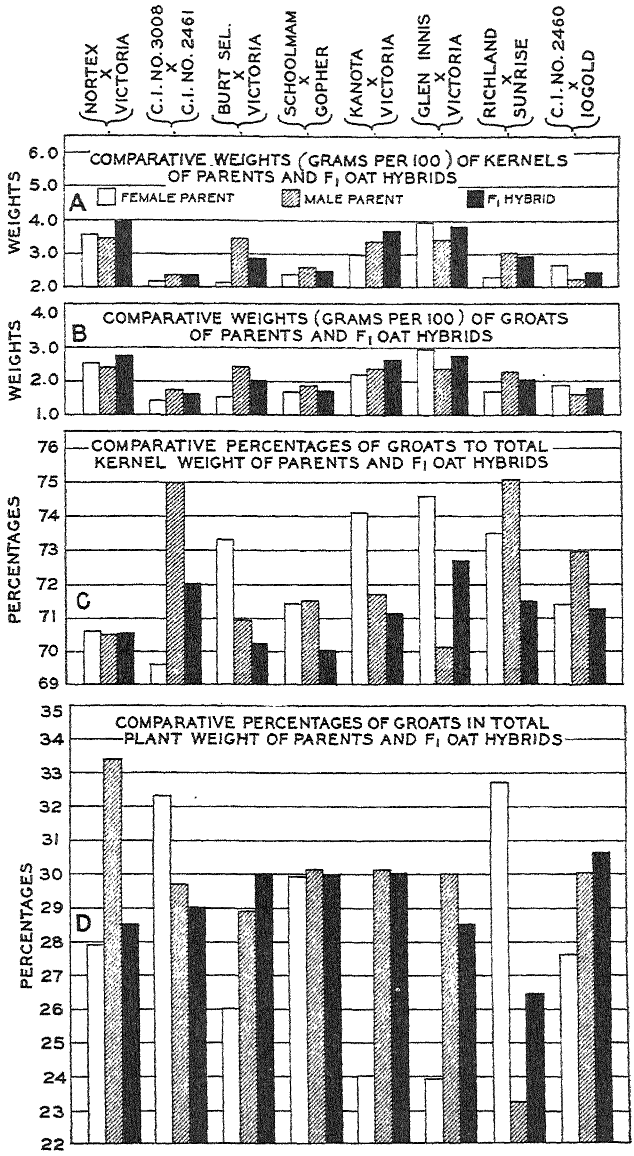

FIG. 3.—Comparison of F_1 hybrid with its parents in weight per 100 kernels (A), weight of 100 groats (B), percentage of groat weight to total weight of kernel (C), and comparative percentages of groats to total weight of plant (D).

TABLE 2.—*Average germination percentages of kernels from F_1 hybrid plants of the parent strains and deviations of the hybrids from their parent lines.*

	Nortex x Victoria	C. I. No. 3008 x C. I. No. 2461	Burt Sel. 2491 x Victoria	Kanota x Victoria	Glen Innis x Victoria	Richland x Sunrise	C. I. No. 2460 x Iogold
Germination of Covered Seed, %							
Parent ♀	98.0	100.0	98.0	100.0	93.0	100.0	99.0
Parent ♂	96.0	100.0	97.0	100.0	99.0	100.0	100.0
Parent average	97.0	100.0	97.5	100.0	96.0	100.0	99.5
Hybrid average	96.7	99.0	98.3	98.7	94.3	98.0	96.7
Ave. dev. from larger parent	—1.3	—1.0	+0.3	—1.3	—4.7	—2.0	—3.3
Both parents	—0.3	—1.0	+0.8	—1.3	—1.7	—2.0	—2.8
Germination of Hulled Seed, %							
Parent ♀	100.0	87.0	96.0	84.0	92.0	94.0	97.0
Parent ♂	98.0	96.0	93.0	100.0	93.0	91.0	98.0
Parent average	99.0	91.5	94.5	92.0	92.5	92.5	97.5
Hybrid average	97.0	94.5	87.3	96.3	82.8	94.0	99.3
Ave. dev. from larger parent	—3.0	—1.5	—8.7	—3.7	—10.2	±0.0	+1.3
Both parents	—2.0	+3.0	—7.3	—4.3	—9.7	+1.5	+1.8

TABLE 3.—*Percentage of increase in certain F_1 hybrids above the mean measurements of their larger parents when grown under comparable conditions.**

Crosses	No. F_1 plants	Characters measured								
		Culm height	Panicle length	No. culms	Total weight			Percentage increase of grain in grain-straw ratio	Total weight	
					Plant	Straw	Grain		100 kernels	100 groats
1927										
Richland x Fulghum	4	13.2	—	17.5	48.5	51.3	35.2	—	—	—
Richland x Markton	4	—	—	—	—	—	18.9	33.8	—	—
Richland x Markton	1	—	—	—	—	—	—	31.6	—	—
Ruakura x Burt sel.	1	8.7	1.9	—	29.6	10.0	53.4	4.9	—	—
No. Finnish x Black Mesdag	5	3.7	0.3	3.1	16.3	14.6	20.9	—	—	—
Swedish Select x Fulghum (fatuoid)	4	—	—	9.1	—	—	—	21.8	—	—
1930										
Nortex x Victoria	3	—	—	1.6	—	6.9	—	—	8.8	8.6
Burt sel. x Victoria	3	—	5.2	—	—	—	—	5.1	—	—
Schoolmam x Gopher	3	—	—	—	—	—	0.5	1.7	—	—
Kanota x Victoria	4	—	—	27.8	—	—	—	0.2	11.4	10.5
Glen Innis x Victoria	4	—	—	8.4	—	12.7	—	3.5	—	—
Richland x Sunrise	3	12.4	—	—	—	4.5	—	—	—	—
C. I. No. 2460 x Iogold	3	—	—	—	17.0	8.6	30.4	4.4	—	—

*Only differences above those of the larger parent are shown.

groat to total kernel weight was less in the hybrid than in the mean of the respective parents and in no case exceeded that of the more efficient parent.

VIGOR OF SEED FROM F_1 PLANTS

Increased germination and subsequent growth frequently are associated with hybridization. In Table 2 are presented data indicating that high germination percentages were obtained from seed of both parents and hybrids. Presumably no lack of compatibility existed in the crosses studied. However, seed of only one hybrid gave higher germination percentages than its better parent. Removal of glumes probably injured the embryo, as reduced germination occurred in hulled seed.

HETEROSIS IN DIFFERENT PLANT PARTS

In Table 3 the data on F_1 hybrids indicate that heterosis is manifested differently in various oat crosses. This deduction is based partly on data previously published.[9] All the data presented were obtained from plants grown by the same methods. In some crosses nearly all measurable plant parts are increased, whereas in others relatively few parts indicate heterosis. The crosses Richland x Fulghum and North Finish x Black Mesdag are representative of the former, while Richland x Markton might be considered as of the latter class. As heterosis may be manifested in only a few parts, it may be considered specific in nature. Heterosis generally is considered genetic, and thus the assumption of linkage is necessary to exclude specificity. Doubtless in some crosses heterosis in one part explains its manifestation elsewhere. An example might be culm height or number of culms and increased straw yield.

DISCUSSION

Although its benefits have been recognized for centuries, little practical use has ever been made of heterosis in breeding cereals, with the exception of corn. Probably more attention could profitably be accorded it.

A study of heterosis discloses its multiple relationships and also its apparent specific nature. Presumably it may affect the plant parts individually. This suggests the genetic independence of size factors, which would be favorable to breeding for specific characters such as greater tillering ability, etc.

In oats, yield of grain often exhibits the influence of heterosis. Granting that heterosis results only when parents differ genetically, this is a hopeful sign, as the existence of numerous factors enhances the possibility of making new combinations. Conversely, some oats presumably already contain so many factors making for increased yield as to preclude exceptional improvement of them by hybridization with others similarly adapted. Victory and Golden Rain are examples of this type.

SUMMARY

Immediate increase in kernel weight apparently resulted from hybridization in oats. Average weight of kernel and of groat on resulting F_1 individuals was also considerably increased.

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[9] See footnote 5.

In plant height and panicle length F_1 oat plants usually exceeded their parental means, and in one cross their larger parent.

Oat hybrids usually contain fewer culms than their parents. Crosses involving Victoria, a profusely tillering variety, usually exceeded Victoria in number of culms.

In weight of total plant, straw, and grain, F_1 oat plants usually exceeded the average of the parents, and in some crosses the larger parent. Increased earliness often occurs in F_1 oat plants and earliness often is associated with reduced plant size; yet not only a proportional increased yield of grain to straw, but an actual increased yield of grain was obtained from some oat hybrids, thus indicating increased functional efficiency of hybrid plants.

The weight of individual glume was increased proportionately more than the weight of groat in F_1 oat kernels. The influence usually was small.

Total groat yield and proportion of groat to total weight of plant usually approached that of the more productive parent.

Heterosis may be observed in a few plant parts in some crosses and in many parts in others. The assumption of linkage is unnecessary to explain these latter cases.

INFLUENCE OF INBREEDING AND SELECTION ON SEED PRODUCTION OF SPACE-ISOLATED MOTHER BEETS[1]

H. L. Kohls and E. E. Down[2]

The influence of continued inbreeding and selection upon the seed production of space-isolated[3] mother beets was studied with strains of sugar beets used in the regular breeding program at this station in 1930, 1931, and 1932. Mother beets isolated in 1930 and 1931 were selected from material inbred zero, one, or two generations. Fifteen mother beets were also isolated in 1930 from lines inbred three generations. The mother beets isolated in 1932 were beets grown from the seed of mother beets isolated in 1930 and represent lines inbred one, two, three, or four generations.

The pedigrees of all lines of these mother beets trace back to selections made from high-producing brands of commercial beet seed included in the variety tests at this station. The pedigrees of mother beets isolated in 1930 and 1931 trace back to these same commercial brands, but they represent different original selections. No data are available to show the seed producing habits of these commercial brands from which the original selections were made; however, no difference in seed production, death rate, failure to send up seed stalks, or total sterility were observed among the selections which were made from the different commercial brands. Mother beets from lines inbred one, two, three, or four generations do not represent random samples of the original selections because mother beets producing no seed are automatically eliminated, and those producing small amounts of seed are not represented as extensively in the following generations as those producing larger quantities of seed. Also, larger populations give the breeder a better chance to study the progeny and, other things being equal, a greater chance to make selections.

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[1] Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal article No. 159 (New Series). Received for publication June 21, 1933.

The experiment was conducted cooperatively with the Division of Sugar Plant Investigations, U. S. Dept. of Agriculture.

[2] Assistant and Research Associate, respectively.

[3] Down, E. E., and Lavis, C. A. Studies on methods for control of pollination in sugar beets. Jour. Amer. Soc. of Agron., 22:1–9. 1930.

The data obtained from 518 mother beets grown in 1930 are shown in Table 1. These data show that the percentage of mother beets that died, or failed to send up seed stalks, are about equal for each generation of inbreeding. The average seed production from mother beets producing seed stalks was 17.95 ± 1.82, 29.98 ± 1.58, 38.58 ± 1.30, and 30.00 ± 3.46 grams of seed for those inbred zero, one, two, and three generations, respectively. The seed yield of mother beets inbred three generations is below that of mother beets inbred two generations, but the difference of 8.58 grams is not statistically significant when measured by the probable error of the difference.

The data given in Table 2 were obtained from 571 mother beets planted in 1931. The percentage of mother beets that died increased as the generations of inbreeding increased. This may possibly be explained by the fact that many of the mother beets inbred one or two generations were smaller in size and less vigorous than those not inbred, and so were more easily killed by the unusually long drought of 1931. The seed yields in 1931 agreed in general with those obtained in 1930, except that the average yield obtained ranged lower by 7.4 to 13.4 grams than was obtained from the corresponding generations the previous season.

The data obtained from 639 mother beets in the plantings of 1932, representing progenies of the selections reported in Table 1, are given in Table 3. The percentage of mother beets that died was very high and may be attributed to two factors, *viz.*, (a) the 1931 season was very dry, consequently the mother beets were very small at harvest time; and (b) the weather remained unusually warm until very late in the fall, and the mother beets started growth in storage. The warm storage conditions caused considerable rotting and the mother beets remaining alive at planting time were in poor condition. The results based on the sugar beets producing seed stalks seem reliable for comparison with the results of previous years. The average seed yields were 11.50 ± 1.74, 16.20 ± 1.12, 19.18 ± 1.44, and 21.47 ± 3.07 grams of seed for the lines inbred one, two, three, and four generations, respectively. The average seed production increased as the number of generations of inbreeding increased. The drop in production shown by the mother beets inbred three generations in 1930 (Table 1) is not shown when these selections were inbred the fourth generation in 1932 (Table 3).

The trend, as inbreeding continues, of average seed production from mother beets, basing judgment only on those mother beets which produce seed stalks, is shown in Fig. 1 Sec. A. These graphs show a general tendency for average seed production to increase with the increase in the number of generations of inbreeding. The only exception is the low seed production of a small population of mother

TABLE 1.—*Seed yields obtained from mother beets space isolated in 1930; plantings made in city gardens in Lansing and Jackson, Michigan.*

Classification of mother beets	Seed production by classes, grams	Number of generations inbred							
		0		1		2		3	
		No. of beets	Per cent of total	No. of beets	Per cent of total	No. of beets	Per cent of total	No. of beets	Per cent of total
Destroyed		0	0.0	12	3.5	3	3.1	1	6.7
Dead		9	12.8	43	12.8	13	13.4	2	13.3
Without seed stalks		0	0.0	4	1.2	0	0.0	0	0.0
With seed stalks	0	10	14.3	31	9.2	8	8.3	3	20.0
With seed stalks	0.01– 10.00	26	37.1	93	27.7	17	17.5	2	13.3
With seed stalks	10.01– 20.00	7	10.0	42	12.5	17	17.5	1	6.7
With seed stalks	20.01– 30.00	6	8.6	30	8.9	7	7.2	2	13.3
With seed stalks	30.01– 40.00	3	4.3	19	5.6	4	4.1	1	6.7
With seed stalks	40.01– 50.00	3	4.3	8	2.4	5	5.2	0	0.0
With seed stalks	50.01– 60.00	3	4.3	10	3.0	5	5.2	0	0.0
With seed stalks	60.01– 70.00	0	0.0	3	0.9	3	3.1	1	6.7
With seed stalks	70.01– 80.00	0	0.0	8	2.4	4	4.1	0	0.0
With seed stalks	80.01– 90.00	3	4.3	8	2.4	1	1.0	2	13.3
With seed stalks	90.01–100.00	—	—	5	1.5	0	0.0	—	—
With seed stalks	100.01–110.00	—	—	4	1.2	3	3.1	—	—
With seed stalks	110.01–120.00	—	—	3	0.9	2	2.1	—	—
With seed stalks	120.01–130.00	—	—	3	0.9	0	0.0	—	—
With seed stalks	130.01–140.00	—	—	4	1.2	2	2.1	—	—
With seed stalks	140.01–240.00	—	—	6	1.8	3	3.0	—	—
Totals		70		336		97		15	
Mean seed weight in grams* Probable error		17.95 ±1.82		29.98 ±1.58		38.58 ±1.30		30.00 ±3.46	
Median seed weight in grams*		8.47		13.45		19.12		20.00	

*Dead and destroyed beets omitted.

TABLE 2.—*Seed yields obtained from mother beets space isolated in 1931, plantings made in city gardens in Lansing, Jackson, Mason, and Charlotte, Michigan.*

Classification of mother beets	Seed production by classes, grams	Number of generations inbred					
		0		1		2	
		No. of beets	Per cent of total	No. of beets	Per cent of total	No. of beets	Per cent of total
Destroyed	—	1	5.6	7	6.3	30	6.7
Dead	—	0	0.0	18	16.2	86	19.5
Without seed stalks	—	0	0.0	0	0.0	2	0.5
With seed stalks	0	5	27.7	12	10.8	33	7.5
With seed stalks	0.01– 10.00	9	50.0	32	28.9	134	30.3
With seed stalks	10.01– 20.00	1	5.6	9	8.1	47	10.6
With seed stalks	20.01– 30.00	0	0.0	10	9.0	31	7.0
With seed stalks	30.01– 40.00	2	11.1	10	9.0	20	4.5
With seed stalks	40.01– 50.00	–	—	3	2.7	11	2.5
With seed stalks	50.01– 60.00	–	—	4	3.6	8	1.8
With seed stalks	60.01– 70.00	–	—	1	0.9	11	2.5
With seed stalks	70.01– 80.00	–	—	0	0.0	4	0.9
With seed stalks	80.01– 90.00	–	—	2	1.8	6	1.3
With seed stalks	90.01–100.00	–	—	0	0.0	4	0.9
With seed stalks	100.01–110.00	–	—	0	0.0	2	0.5
With seed stalks	110.01–120.00	–	—	2	1.8	4	0.9
With seed stalks	120.01–130.00	–	—	0	0.0	2	0.5
With seed stalks	130.01–140.00	–	—	0	0.0	2	0.5
With seed stalks	140.01–320.00	–	—	1	0.9	5	1.1
Totals		18		111		442	
Mean seed weight in grams*		9.12		22.56		25.15	
Probable error		±1.11		±2.05		±1.42	
Median seed weight in grams*		6.07		9.77		9.70	

*Dead and destroyed beets omitted.

beets in the 1930 plantings which were inbred three generations. It is to be noted that the results obtained in 1932 from selections of these low-producing 1930 lines, i.e., those with four generations of inbreeding, show the tendency for increased seed production.

Since seed yields obtained in pedigreed lines are extremely variable, the median appears to furnish better values for comparisons of seed yield, from year to year, than the mean. Graphs based on median values for seed production for each of the 3 years are shown in Fig. 1 Sec. A. Judgment based on the median values indicates also that as the number of generations of inbreeding and selection continue, seed production increases. The mother beets inbred three times which were planted in 1930 gave a median which did not show the drop, in comparison with the mother beets inbred two generations,

TABLE 3.—*Seed yields obtained from mother beets space isolated in 1932, plantings made in city gardens in Lansing, Jackson, Mason, Charlotte, and Owosso, Michigan.*

Classification of mother beets	Seed production by classes, grams	Numbers of generations inbred							
		1		2		3		4	
		No. of beets	Per cent of total	No. of beets	Per cent of total	No. of beets	Per cent of total	No. of beets	Per cent of total
Destroyed		5	7.3	28	7.9	19	10.3	5	15.6
Dead		44	63.8	122	34.5	67	36.4	10	31.2
Without seed stalks		1	1.4	12	3.4	11	6.0	0	0.0
With seed stalks	0	1	1.4	17	4.8	9	4.9	2	6.3
With seed stalks	0.01– 10.00	12	17.5	100	28.3	33	17.9	6	18.8
With seed stalks	10.01– 20.00	2	2.9	34	9.6	14	7.6	1	3.1
With seed stalks	20.01– 30.00	2	2.9	15	4.2	9	4.9	3	9.4
With seed stalks	30.01– 40.00	1	1.4	9	2.5	7	3.8	1	3.1
With seed stalks	40.01– 50.00	1	1.4	4	1.1	4	2.2	3	9.4
With seed stalks	50.01– 60.00	—	—	3	0.8	3	1.6	0	0.0
With seed stalks	60.01– 70.00	—	—	2	0.6	2	1.2	1	3.1
With seed stalks	70.01– 80.00	—	—	1	0.3	5	2.7	—	—
With seed stalks	80.01– 90.00	—	—	1	0.3	1	0.5	—	—
With sedd stalks	90.01–100.00	—	—	3	0.8	—	—	—	—
With seed stalks	100.01–110.00	—	—	1	0.3	—	—	—	—
With seed stalks	110.01–160.00	—	—	2	0.6	—	—	—	—
Totals		69		354		184		32	
Mean seed weight in grams* Probable error		11.50 ±1.74		16.20 ±1.12		19.18 ±1.44		21.47 ±3.07	
Median seed weight in grams*		7.31		3.93		11.07		15.00	

*Dead and destroyed beets omitted.

shown in the previous set of graphs based on the mean seed production.

The percentage of mother beets (with seed stalks) producing from 0 to 10 grams of seed for the years 1930, 1931, and 1932 are shown in Fig. 1 Sec. B. A rather high percentage of mother beets inbred zero generations produce less than 10 grams of seed. As inbreeding continues through two generations the percentage of mother beets falling into this low-producing group decreased, except in 1931 where a slight rise is shown. The material upswing shown in the 1930 results by those mother beets inbred three times was not continued by their offspring in the 1932 plantings.

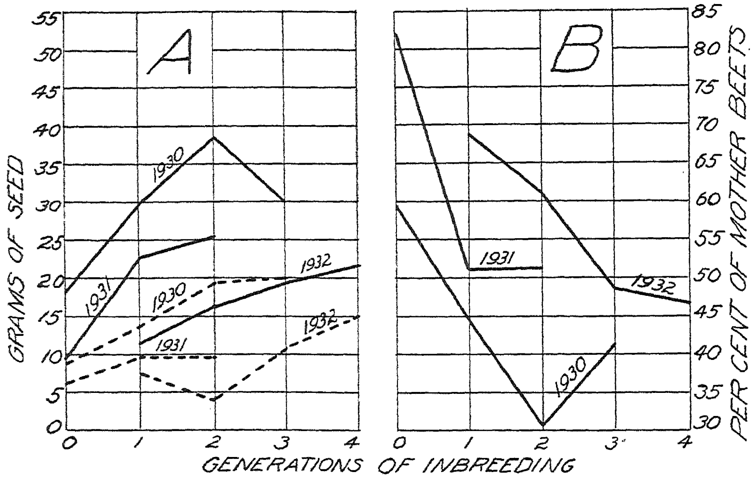

FIG. 1.—Only mother beets with seed stalks are included. A, seed yields per isolated mother beet. —— Mean. - - - Median. B, percentage of mother beets that produced from 0 to 10 grams of seed.

The data presented indicate that inbreeding and selection of mother beets result, for a time at least, in an increase in the average production of seed per mother beet. This increase may largely be the result of automatic elimination of self-sterile mother beets and the elimination of partly sterile mother beets by selection.

INFLUENCE OF THE CARBON-NITROGEN RATIOS OF ORGANIC MATTER ON RATE OF DECOMPOSITION IN THE SOIL[1]

IMRI J. HUTCHINGS AND THOMAS L. MARTIN[2]

When organic matter is added to the soil, decomposition begins and CO_2, NH_3, and NO_3 are produced. The rate at which the added material decays depends largely upon the soil environment, the type of organisms involved, and chemical composition of the organic matter added.

There has been found a relationship between the C-N ratio of the organic materials and the ease of decomposition (3, 6, 9, 10, 13).[3] The narrower the ratio, the more rapid the decay and vice versa. Therefore, if organic materials of different composition were narrowed or widened to the same C-N ratios by the addition of various substances, then they should decompose at approximately the same rate. The following experiments were designed and carried out for the purpose of throwing light on this question.

PROCEDURE

Soil having a pH of 7.4, a total N content of 0.147%, and classified by Sanchez (12) as a Jordan loam, was used. The total N was determined by the Kjeldahl method and the total C by the method of Degtjareff (1). The C-N ratios were found to be as follows: alfalfa tops, 17.5 : 1; alfalfa roots, 28.4:1; sweet clover tops, 16.4 : 1; sweet clover roots, 27.4 : 1; and wheat straw, 82 : 1.

The investigation consisted of three experiments as follows. In experiment I, dried and ground sweet clover tops were added to soil at the rate of 1% and 100 grams of the mixture were placed in 1-pint milk bottles. Water was added to bring the moisture content to 66% of the moisture-holding capacity. The soil was then incubated at 28° C and aspirated for 40 minutes each day for 30 days. The CO_2 evolved was determined according to the method of Waksman and Starkey (14). To study the rate of NO_3 accumulation sweet clover tops were added to 1 kg of soil in 1% quantities and the mixture placed in fruit jars. The moisture was brought to optimum and the whole incubated at 28° C. Samples were withdrawn and analyzed every second day for 30 days according to the method of Harper (2). The same method of procedure was repeated with the sweet clover roots, alfalfa tops and roots, and wheat straw studies.

In experiment II the C-N ratios of sweet clover roots and tops, alfalfa roots and tops, and wheat straw were all narrowed to 10:1 by the addition of $NaNO_3$. All the other details of the experiment were identical with experiment I.

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[2] Graduate Student in Soils and Professor, respectively.

[3] Numbers in parenthesis refer to "Literature Cited," p. 341.

In experiment III the above procedure was repeated except the C-N ratios were widened to 80:1 by the addition of cellulose in the form of filter paper. The filter paper was grated on a hand grater and rendered very fluffy.

All treatments and analyses were done in duplicate. The results secured in the various experiments are shown in Tables 1, 2, 3, 4, 5, and 6.

DISCUSSION

EXPERIMENT I

From Table 1 it may be noticed that there was very little CO_2 evolution at any time from the untreated soil, and that up to about the tenth day, when the very active period was past, the straw-treated soil evolved only a fraction as much as did the soils treated with legume roots or tops. During the first 5 days sweet clover tops and roots and alfalfa tops when added to the soil caused CO_2 to evolve at approximately the same rates, but the amount from soil treated with alfalfa roots was distinctly lower than from the soil with the other legume treatments. The maximum rate of evolution was reached by the third day by all of the soils treated with legumes except that treated with alfalfa tops, which reached its maximum 1 day later, the same time as the straw-treated soil. This delayed reaction of the alfalfa tops as compared with the other legume treatments, continued throughout the first week of the experiment, and was very likely due to differences in the chemical composition of the materials applied.

TABLE 1.—*Milligrams of carbon dioxide evolved when organic materials were allowed to decompose in the soil.*

Days	Alfalfa tops	Alfalfa roots	Sweet clover tops	Sweet clover roots	Wheat straw	Check
1......	16.1	13.8	16.7	19.0	7.0	1.0
2......	22.8	17.5	25.8	25.9	7.0	2.0
3......	24.0	15.0	23.2	25.0	8.0	0.0
4......	16.0	10.0	18.5	17.0	5.0	0.3
5......	14.0	5.0	21.0	16.5	4.0	0.4
6......	10.4	5.9	20.5	16.4	5.0	0.4
7......	11.4	7.2	13.5	14.0	4.2	2.3
8......	10.2	7.6	10.0	8.0	3.3	0.5
9......	9.1	8.8	9.3	8.0	4.1	0.9
10......	6.0	5.7	6.5	6.6	3.7	1.2
11......	5.0	7.1	6.9	7.6	5.0	1.8
12......	4.7	4.9	5.5	4.6	3.0	1.5
13......	4.0	5.2	4.9	3.8	3.3	0.2
14......	4.4	4.7	5.0	3.8	3.0	0.5
15......	4.0	4.0	4.9	4.0	3.2	1.0
16......	3.8	4.7	5.1	5.4	3.0	1.1
17......	2.8	2.8	2.0	2.2	1.0	0.0
22......	2.8	2.8	2.0	2.2	1.0	0.5
23......	2.8	3.3	3.6	2.7	2.0	1.5
25......	2.5	3.3	2.4	1.8	2.1	1.0
27......	1.5	2.6	1.0	1.0	1.6	0.5

The data also show that whereas the rate of CO_2 evolution in the soils treated with either alfalfa tops or roots declined rather uniformly for the first few days after the maximum rate had been reached, a stage was reached on the sixth and seventh days when there was an arresting of this decline in the soils treated with either tops or roots of sweet clover. This was probably due to some equilibrium favorable to the microflora.

According to Martin (6), the narrower the ratio the more rapid the decomposition as measured by CO_2 evolution. It may be noticed, however, that the soil treated with sweet clover roots with a N content of 2.1% evolved as much CO_2 as that treated with sweet clover tops and alfalfa tops with 3.8 and 3.2% N, respectively. This may be partially explained by the fact that there was a larger amount of water-soluble N in the sweet clover roots than in the alfalfa tops and roots and sweet clover tops. The water-soluble N was 300% greater in sweet clover roots, 190% greater in sweet clover tops, and 150% greater in the alfalfa tops than in the alfalfa roots. These results are in agreement with those of Whiting and Richmond (16) who found that 86.6% of the N contained in the sweet clover roots is water-soluble, whereas only 37.3 and 33.3%, respectively, is water-soluble in the stems and leaves.

It is evident that the amount of CO_2 produced was affected not only by the C-N ratio but also to a large extent by the amount of water-soluble N in the various materials used. The order of decomposition as measured by the rapidity with which CO_2 was evolved is sweet clover roots, sweet clover tops, alfalfa tops, alfalfa roots, and straw.

It may be noted from the results of the nitrate determination as shown in Table 2 that in general the NO_3 accumulated in the following order: Sweet clover tops, alfalfa tops, sweet clover roots, alfalfa roots, check, and straw. This is in the order of the C-N ratios of these substances as indicated in the total N determinations in which sweet clover tops, alfalfa tops, sweet clover roots, alfalfa roots, and straw had the following percentages of N, respectively, 3.8, 3.2, 2.1, 1.8, and 0.3.

TABLE 2.—*Parts per million of nitrates accumulated when organic materials were allowed to decompose in the soil.*

Days	Alfalfa tops	Alfalfa roots	Sweet clover tops	Sweet clover roots	Wheat straw	Check
3......	Trace	Trace	Trace	Trace	Trace	16.4
5......	Trace	9.8	Trace	Trace	Trace	13.2
7......	16.3	33.3	10.4	7.5	Trace	Trace
10......	42.4	40.0	28.0	42.0	Trace	5.0
12......	164.0	66.7	220.0	164.0	Trace	20.8
14......	200.0	64.0	248.0	200.0	Trace	31.2
17......	200.0	50.0	220.0	200.0	Trace	6.8
19......	200.0	52.4	200.0	220.0	Trace	16.8
24......	248.0	80.0	248.0	200.0	Trace	16.4
26......	248.0	80.0	220.0	181.6	Trace	20.0
29......	220.0	80.0	220.0	164.0	Trace	18.1

It is evident that as the CO_2 evolution diminished NO_3-N began to accumulate. Apparently certain organisms grew vigorously during the period of excessive evolution of CO_2 and the NO_3 were used by them for protoplasmic building. After available carbohydrates and NO_3 were used, there was a cessation of mold development and CO_2 evolution, resulting in an accumulation of NO_3.

In the soils treated with the alfalfa tops and roots the period of most rapid production of CO_2 was passed more quickly than in the clover-treated soil, but the latter soil reached its maximum NO_3 content more quickly than did the others.

The amount of NO_3-N accumulated in the soils treated with alfalfa tops, sweet clover tops, and sweet clover roots was comparatively high. This is perhaps due to the narrow C-N ratio of the materials added to the soil. This narrow ratio explains why the NO_3 content of the soil treated with alfalfa roots is lower than that of the other materials. The straw-treated soil was even lower than the untreated soil in NO_3 content, a fact which might be explained by the excessively wide C-N ratio and the probability that the available N was used by molds. It confirms previous work done in this laboratory (7).

EXPERIMENT II

It may be noted in Table 3 that the CO_2 evolution was approximately twice as vigorous during certain periods when the C-N ratio of all materials was narrowed to 10:1 as in experiment I when the original materials were used. The peak of CO_2 production was reached about 1 day sooner with all substances and also diminished more rapidly, finishing the rapid stage in about 8 days, or 1 day

TABLE 3.—*Milligrams of carbon dioxide evolved when C-N ratios of organic materials were narrowed to 10:1 with sodium nitrate.*

Days	Alfalfa tops	Alfalfa roots	Sweet clover tops	Sweet clover roots	Wheat straw	Check
1......	25.9	26.2	28.9	28.9	16.6	9.6
2......	30.5	29.6	36.3	37.5	11.0	4.6
3......	19.2	19.7	27.9	25.8	8.6	2.4
4......	17.4	17.4	21.7	21.2	12.9	4.5
6......	10.4	13.4	10.4	15.5	11.2	4.5
7......	9.9	11.8	9.8	12.6	9.0	3.4
8......	7.2	10.2	9.5	10.3	6.3	2.9
9......	8.5	8.2	8.9	8.5	8.2	2.9
10......	9.8	9.9	10.7	10.4	9.4	3.0
11......	9.6	10.4	10.6	10.9	9.0	2.3
13......	9.4	11.2	13.0	12.4	10.7	5.6
14......	3.5	4.9	5.3	5.5	6.3	2.1
15......	4.3	5.7	4.6	4.1	5.7	2.2
16......	6.1	7.3	4.6	7.9	8.4	3.0
17......	6.5	6.8	6.0	7.5	7.3	2.3
20......	6.9	8.9	6.8	6.8	8.3	4.0
21......	3.2	3.6	2.7	2.5	3.8	2.2
22......	3.4	3.2	3.4	2.3	3.4	2.3
23......	3.0	2.9	1.8	1.8	2.1	1.8
24......	3.4	3.4	3.4	2.9	3.1	2.3
25......	3.4	3.2	2.3	2.7	3.4	2.3
28......	2.4	2.4	2.7	2.5	3.0	1.2
29......	1.9	2.0	2.0	1.2	2.1	1.2

earlier than was found in the first experiment. A notable fact shown in the data is that when the C-N ratio was narrowed by the addition of $NaNO_3$ the CO_2 evolution of the soil treated with alfalfa roots and that with alfalfa tops was almost identical, whereas under natural conditions there was considerable difference between the two. Also, the differences in the rate of decrease in CO_2 evolution between alfalfa and sweet clover treated soils was not as noticeable as it was in experiment I.

It is obvious that the addition of available N in the form of $NaNO_3$ stimulated microbial growth. Still there are some differences in the rate of CO_2 evolution even though the C-N ratios have been equalized throughout. There is an indication that the chemical composition of the plant materials, such as form of N and other constituents, has as great influence as the total amount of N present. Narrowing the ratio with available N stimulated more rapid decomposition, but the rate of decomposition of the various substances was probably also influenced by the characteristic physical and chemical properties of the various plant materials incorporated in the soil. This was also found by Martin (8).

By comparing the data in Tables 3 and 4 it may be noted that the NO_3 accumulation appeared after the CO_2 evolution had decreased considerably. This agrees with results obtained in the first experiment. However, the NO_3 did not begin to accumulate rapidly until the tenth to the fifteenth day. This is a delay of approximately a week, as compared with the results of the first experiment where no $NaNO_3$ was added. However, there was some accumulation from the beginning indicating that there was more than enough N present to satisfy the bacterial needs. Furthermore, during the first week or 10 days there was more N available in the straw-treated soil than in the soils treated with any of the other organic materials except in that treated with alfalfa roots, yet there was very little decomposition of the straw during the period, as indicated by CO_2 evolution. The fact that during the first 14 days N was available in all soils indicates that the $NaNO_3$ added was not being used. After the first 14 days

TABLE 4.—*Parts per million nitrates accumulated when C-N ratios of organic materials were narrowed to 10:1 with sodium nitrate.*

Days	Alfalfa tops	Alfalfa roots	Sweet clover tops	Sweet clover roots	Wheat straw	Check
3......	8.6	50.0	11.0	8.6	32.5	8.2
5......	8.6	48.0	15.0	9.0	40.0	20.0
7......	14.7	52.0	27.6	10.8	64.0	38.4
9......	40.0	62.4	28.0	29.4	55.6	22.8
11......	32.8	74.0	10.0	23.2	50.0	10.0
13......	90.8	64.4	52.4	23.2	33.2	10.0
15......	166.4	100.0	200.0	10.0	100.0	10.0
18......	164.0	149.0	164.0	Trace	76.8	Trace
20......	100.0	200.0	250.0	31.2	110.8	Trace
22......	166.4	200.0	200.0	31.2	21.7	Trace
24......	200.0	200.0	200.0	40.0	80.0	Trace
27......	200.0	200.0	200.0	40.0	80.0	Trace
29......	142.8	200.0	200.0	40.0	90.8	Trace

the NO_3 content of all soils except the check became higher. This was due, on the one hand, to rapid nitrification of the organic nitrogen of the plant constituents, and on the other, to the fact that the carbonaceous material had been about used up, the organisms of decomposition thus having little use for the added NO_3. Hence, the addition of $NaNO_3$ to the soils along with the various plant materials gave larger amounts of NO_3-N in all cases than in the first experiment where $NaNO_3$ was not used.

The amount of NO_3 accumulated in soil treated with sweet clover roots was very small. Apparently, the available N in the sweet clover roots was used to advantage in conjunction with $NaNO_3$, for the NO_3 did not accumulate to any appreciable extent. Just the opposite effect was produced by the alfalfa roots, considerably larger amounts of NO_3 accumulating where $NaNO_3$ was added with the alfalfa roots than where alfalfa roots were applied alone. These differences are perhaps due to the differences in the chemical composition of the non-nitrogenous materials in the alfalfa and sweet clover roots. The amount of NO_3-N in the soils varied considerably after the fifteenth day. According to Lipman and Brown (5), the periodicity in the accumulation of NO_3 in the soil may be due to the temporary prominence of species especially capable of transforming large amounts of NO_3 into protein N, as well as to more rapid increase of various decay organisms and their intense utilization of NO_3 for the building of their bodies. This is in all probability the cause of these fluctuations.

EXPERIMENT III

In Table 5 it may be seen that where the C-N ratios were widened to 80:1 that the amount of CO_2 evolved during the first few days was

TABLE 5.—*Milligrams of carbon dioxide evolved when C-N ratios of organic materials were widened to 80:1 with cellulose.*

Days	Alfalfa tops	Alfalfa roots	Sweet clover tops	Sweet clover roots	Wheat straw	Check
1......	19.7	18.9	19.0	19.4	9.1	2.4
2......	23.5	22.7	23.5	28.2	9.0	2.8
3......	25.6	18.5	26.5	26.6	7.2	4.0
4......	26.0	18.0	26.0	20.7	7.5	3.8
5......	23.7	13.5	22.8	20.0	5.9	2.9
9......	15.0	13.0	19.0	17.2	3.9	2.2
10......	11.7	12.0	12.5	20.0	4.6	1.1
11......	12.8	12.0	12.0	18.0	6.5	2.5
12......	11.0	9.5	10.0	13.0	5.5	2.5
15......	10.0	4.0	10.5	11.0	5.0	2.0
16......	8.4	7.0	8.5	9.2	4.5	2.8
17......	7.0	7.5	7.0	7.0	4.3	1.4
18......	8.4	9.2	8.8	10.0	4.7	1.8
19......	8.6	9.2	7.5	11.4	6.5	1.5
20......	5.5	6.0	5.7	10.2	4.0	1.5
23......	4.0	4.8	4.0	7.0	2.2	1.0
24......	4.0	5.5	5.5	6.0	4.5	1.0
25......	4.5	5.5	3.5	5.1	5.0	1.0
28......	8.0	6.5	6.8	5.1	8.8	1.4
29......	5.0	4.0	4.5	9.0	4.5	1.2

somewhat similar to that produced in experiment I,where the organic materials had received no additions to modify the C-N ratios. However, the extent of CO_2 evolution was sustained for a longer period of time than in experiment I. There was slightly more CO_2 produced in this experiment, due probably to the fact that there was a larger proportion of carbonaceous material. In addition the loose nature of the cellulose added probably loosened the soil to some extent, thus causing better aeration.

The widening of the C-N ratio by the addition of sufficient cellulose to make it 80:1, equal to that of straw, did not seem to equalize the rate of CO_2 evolution. This is evident by comparing the data for sweet clover tops, sweet clover roots, alfalfa tops, and alfalfa roots with that of straw. It again appears that the C-N ratio alone is not the principal factor, but that the chemical constituents making up the organic materials is also an important factor in determining the rate of decomposition. Jodidi and Wells (4) found that the rapidity of decomposition was dependent upon the character and amount of organic matter present. Waksman and Tenny (15) also found this to be the case.

The data in Table 6 show that very little NO_3 accumulation occurred in the soils treated with alfalfa roots and with straw compared with that produced in the two previous tests. This indicates that in the decomposition of the cellulose the small amount of NO_3 present was perhaps assimilated by the organisms of decomposition. This is in agreement with Sievers (10, 11) and Martin (6).

TABLE 6.—*Parts per million of nitrates accumulated when C-N ratios of organic materials were widened to 80:1 with cellulose.*

Days	Alfalfa tops	Alfalfa roots	Sweet clover tops	Sweet clover roots	Wheat straw	Check
2......	Trace	Trace	Trace	Trace	Trace	Trace
6......	10.8	6.6	9.8	7.8	Trace	15.6
8......	18.4	8.6	43.2	62.4	Trace	26.8
10......	45.2	8.6	76.8	100.0	Trace	9.2
12......	60.0	Trace	96.0	110.8	Trace	12.0
14......	80.8	Trace	110.8	82.8	Trace	Trace
16......	96.0	Trace	128.0	87.2	Trace	13.6
19......	142.8	Trace	153.6	100.0	Trace	20.0
21......	133.2	Trace	142.8	119.2	Trace	13.6
23......	142.8	Trace	142.8	110.8	Trace	16.8
25......	142.8	Trace	166.4	119.2	Trace	20.0
27......	166.4	Trace	166.4	133.2	Trace	16.6
29......	166.4	Trace	166.4	142.8	Trace	11.0

Comparing the alfalfa root data in experiment III with those in experiments I and II, it may be observed that when N was available and the percentage of cellulose low, the NO_3 were present in more than sufficient quantities to satisfy the needs of the microorganisms. In experiment III when cellulose was added there was not enough available N to allow NO_3 accumulation.

In examining the straw data in experiment II it may be seen that there has been considerable NO_3 accumulation. Apparently there has been more than enough available N to satisfy the requirement of the micro-organisms. On the other hand, in experiment III the amount of NO_3 accumulated in the straw-treated soil was very slight, indicating that the N available had been used by the organisms.

It will be noted in the sweet clover root data in experiment III that between the sixth and twelfth days NO_3 tends to accumulate more than in the soils treated with sweet clover tops and alfalfa tops. This may be explained on the basis of the higher water-soluble N content in the sweet clover roots. The sweet clover roots mixed with slowly decomposable cellulose probably contained more available N than could be used by the organisms at this time. Cellulose is less readily decomposed than sugars and starches according to Waksman (13). Due to the slower availability of cellulose it evidently took a longer period for the N to be utilized. After the twelfth day the organisms used the available N and the amount of NO_3 accumulated dropped below that of the soil treated with sweet clover and alfalfa tops.

Comparing the NO_3 data of alfalfa tops and sweet clover tops in experiment III, one would expect that because more cellulose was added to the sweet clover tops there would be a smaller accumulation of NO_3, but the opposite was the case. The water-soluble N in sweet clover tops is higher than in alfalfa tops and it may be that there was more than enough to satisfy the N requirements of the micro-organisms, thus permitting an accumulation of NO_3.

The following conclusions may be drawn from these experiments:

SUMMARY AND CONCLUSIONS

1. When alfalfa and sweet clover roots and tops and straw are added to soil that as the CO_2 evolution decreases NO_3 accumulation increases.
2. That the addition of $NaNO_3$ to narrow the ratio stimulates CO_2 evolution during the first few days.
3. That the addition of $NaNO_3$ delays the maximum accumulation of NO_3 for a time.
4. That where $NaNO_3$ was added the alfalfa roots and straw-treated soils showed greater NO_3 accumulation, due either to increased nitrification or decreased NO_3 assimilation.
5. That NO_3 accumulation was depressed through the 30-day period for alfalfa and sweet clover tops and sweet clover roots when cellulose was used to widen the C-N ratio.
6. That NO_3 accumulation in the soil treated with the sweet clover roots was depressed when $NaNO_3$ was used to narrow the C-N ratio.
7. That the use of $NaNO_3$ to narrow the C-N ratio of straw tended to cause an accumulation of NO_3.
8. That the narrowing of the C-N ratio to 10:1 and widening it to 80:1 by means of $NaNO_3$ and cellulose, respectively, using alfalfa tops and roots, sweet clover tops and roots, and straw, influenced very little the relative rate at which these materials decomposed as measured by CO_2 evolution. These facts indicate that the chemical composition of the material is a very important factor to be considered when discussing the rate at which organic matter decomposes.

LITERATURE CITED

1. DEGTJAREFF, W. TH. Determining soil organic matter by means of hydrogen peroxide and chromic acid. Soil Science, 29:239–245. 1930.
2. HARPER, H. J. The accurate determination of nitrates in soils. Jour. Ind. Eng. Chem., 16:180–183. 1924.
3. JENSEN, H. L. On the influence of carbon: nitrogen ratios of organic material on mineralization of nitrogen. Jour. Agr. Sci., 19:71–82. 1929. Abs. in Exp. Sta. Rec., 61:507. 1929.
4. JODIDI, S. L., and WELLS, A. A. Influence of various factors on decomposition of soil organic matter. Iowa Agr. Exp. Sta. Res. Bul. 3. 1912.
5. LIPMAN, J. G., and BROWN, P. E. Experiments on ammonia and nitrate formation in soils. Cent. f. Bakt., II, 26:590–632. 1910. Abs. in Exp. Sta. Rec., 23:621. 1910.
6. MARTIN, T. L. Effect of straw on the accumulation of nitrates and crop growth. Soil Science, 20:159–164. 1925.
7. ——————. The effect of sweet clover and alfalfa roots and tops on the fungus flora of the soil. Soil Science, 27:399–405. 1929.
8. ——————. Influence of chemical composition of organic matter on rate of decomposition. Jour. Amer. Soc. Agron., 25:341–346. 1933.
9. MERKLE, F. G. The decomposition of organic matter in soils. Jour. Amer. Soc. Agron., 10:281–302. 1918.
10. SIEVERS, F. J. Thirty-second annual report. Wash. Agr. Exp. Sta. Bul. 175:40–42. 1922.
11. ——————. Thirty-third annual report. Wash. Agr. Exp. Sta. Bul. 180:49–55. 1923.
12. SANCHEZ, A. M. Soil survey of Provo Area, Utah. U. S. D. A. Bur. of Soils. 1903.
13. WAKSMAN, S. A. Principles of Soil Microbiology. Baltimore: Williams and Wilkins. 1926. (Pages 513–514.)
14. ——————, and STARKEY, R. L. Microbiological analysis of soil as an index of soil fertility: VII. Carbon dioxide evolution. Soil Science, 17:141–161. 1924.
15. ——————, and TENNY, F. G. Composition of natural organic materials and their decomposition in the soil. III. The influence of nature of plant upon the rapidity of its decomposition. Soil Science, 26:155–171. 1928.
16. WHITING, A. L., and RICHMOND, T. E. The relative rates of nitrification of different parts of sweet clover plants. Soil Science, 24:31–38. 1926.

A NEW TABLE OF ODDS BASED ON STUDENT'S TABLE OF PROBABILITY[1]

S. R. MILES[2]

This is a plea for the use of the simplest and most easily understood methods of indicating the significance or reliability of the results of a research. A new table of odds is given to help in attaining this objective. Measures of significance are used to indicate how much confidence can be placed in a result. The measure of significance used should be such that it can be easily understood even by persons who do not understand the basis nor the methods for calculating measures of significance.

The result of an investigation is often given by the use of a statistical constant such as a mean (arithmetic average), a mean differ-

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[1] Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. Published with the approval of the Director of the Station. Received for publication July 3, 1933.

[2] Assistant in Agronomy.

TABLE 1.—*Cases in which the table of odds is useful, with formulas and references*

The case or constant, its symbol, its formula, and references	The standard error of the case or constant, its symbol, its formula, and references	Number of degrees of freedom, df
A	B	C
An Individual Value		
X	$\sigma_X = \sqrt{\frac{\Sigma X^2 - nM^2_X}{n-1}}$	$n-1$
A Standard Deviation		
$\sigma_X = \sqrt{\frac{\Sigma X^2 - nM^2_X}{n-1}}$	$S_\sigma = \frac{\sigma}{\sqrt{2n}}$	$n-1$
A Mean		
$M_X = \frac{\Sigma X}{n}$	$S_M = \sqrt{\frac{\Sigma X^2 - nM^2_X}{n(n-1)}} = \frac{\sigma_X}{\sqrt{n}}$ *	$n-1$
A Mean of Differences (Student's pairing method) (3; 5; 2, sec. 23, 24)		
$M_D = \frac{\Sigma D}{n}$	$S_{M_D} = \sqrt{\frac{\Sigma D^2 - nM^2_D}{n(n-1)}} = \frac{\sigma_D}{\sqrt{n}}$*	$n_D - 1$
A Difference Between Means		
$M_X - M_Y$	$S_{M_X - M_Y} = \sqrt{S^2_{M_X} + S^2_{M_Y}}$ **	$n_x + n_y - 2$
The Deviation for the Binomial Method (4)		
$d = m - \frac{n}{2} - 0.5$	$S_d = \frac{\sqrt{n}}{2}$	Infinity
Coefficient of Regression		
$b_{yx} = \frac{\Sigma(XY) - nM_xM_y}{\Sigma X^2 - nM^2_x}$	$S_{b_{yx}} = \sqrt{\frac{(\Sigma Y^2 - nM^2_y)\ (1-r^2)}{(\Sigma X^2 - nM^2_x)\ (n-2)}}$	$n-2$
Coefficient of Correlation (1, p. 256) (2, sec. 33, 34)		
$r_{xy} = \frac{\Sigma(XY) - nM_xM_y}{\sqrt{(\Sigma X^2 - nM^2_x)\ (\Sigma Y^2 - nM^2_y)}}$	(a) $S_r = \sqrt{\frac{1-r^2}{n-2}}$ *** † (b) $S_r = \frac{1-r^2}{\sqrt{n-1}}$ *** †	$n-2$†
Fisher's z Transformation of r (2, sec. 35)		
$z_{xy} = \log_e \sqrt{\frac{1+r}{1-r}}$‡	$S_z = \frac{1}{\sqrt{n-3}}$	Infinity

Symbols not explained in the table:
A subscript indicates to what the constant applies.
σ, the standard deviation; used for individual values.
S, the standard error (the standard deviation of estimates of a constant).
x, (small *x*) the difference between the estimated value of the constant and any other selected value; therefore, a deviation.
X or Y, (capitals) an individual value of the variable X or Y, or the variable itself.
Σ, sum of.
M, mean (arithmetic average).
n, number of values of a variable, or number of pairs of values for *b* or *r*.
D, the difference for a pair of values; used in Student's pairing method.
m, number of differences with the same sign as the mean difference.
$\log_e$, the natural logarithm, with the base 2.718.

ence, a coefficient of regression, or a coefficient of correlation. The significance of the value of the constant as *estimated* from a sample may be indicated by giving the *standard error* or the *probable error* of the constant or by stating the *odds* or the *probability* that the *true value* of the constant lies within stated limits. These limits are given with reference to the estimated value. The *true value* of a constant is the value which would be secured if the research were conducted with the entire universe or population which is represented by the sample actually used.

Several eminent statisticians have pointed out the advantages of the use of the standard error instead of the probable error. It therefore seems desirable to largely or entirely abandon the use of the latter. However, the use of the probable error is so common that when the standard error is used this fact should be noted in parenthesis.

There are many research men as well as others who wish to study the results of research who are not familiar with statistical methods. Such persons do not comprehend the meaning of the standard error nor of the probable error. The significance of results can be made much clearer by the more frequent use of odds or of probabilities. Odds are preferable to probabilities because odds are more easily understood. Almost anyone clearly comprehends such a statement as, "the odds are 25 to 1 (25:1) that treatment A is better than treatment B under conditions like those of this test." Some such simple and full statement is highly desirable in connection with the more important results reported in a scientific paper in order that a maximum number of persons may clearly understand the real significance of the results. Usually it is well to give the standard error as well as the odds.

THE TABLE OF ODDS AND ITS USE

One reason for the infrequent use of odds heretofore is that the tables of odds which have been available could be used for special cases only. Table 2, in this paper, can be used for studying the significance of an estimated value of any constant or variable whose estimated values are known to be or are assumed to be normally distributed in large samples.

Better formulas for nM^2 are $(\Sigma X)^2/n$ or (M) (ΣX).

In any of the formulas containing the expression $\Sigma X^2 - nM^2x$ (or Y instead of X), X (or Y) can be the deviation of an individual value or of a class center from any assumed mean; then M is the deviation of the true mean from the assumed mean.

* $\sqrt{n-1}$ should be used here if n was used as the divisor in calculating σ, as is very common.

**This formula is correct only when there is no correlation between the values of the two variables. When there is correlation, use Student's pairing method.

***(A) When n is less than about 100:
  (1) Use formula (a), but only to determine the odds that the true correlation exceeds zero.
  (2) To determine the odds that the true correlation exceeds a given value, lies between certain limits, or that two observed correlations indicate a real difference, use Fisher's z transformation of r which is given above.
(B) When n is greater than about 100:
  (1) Use formula (b) for any test of r, except
  (2) Use Fisher's z transformation when r approaches ± 1.

†The formula for the standard error of a partial correlation coefficient is the same as for a total correlation coefficient, and the number of degrees of freedom is n minus 2 minus the number of variables eliminated.

‡The transformation from the r to the z value, or vice versa, is most easily accomplished by the use of Fisher's (2) Table V. B

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TABLE 2.—*Odds that the true value of a statistical constant lies (on a scale of [illegible] between a point at any selected distance (x) from the value of the constant as estimated from a sample and infinity on the opposite side of the estimated [illegible] for various degrees of freedom and for various values of t from zero to six.**

$t = \frac{x}{S}$‡	df=1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Infinity
0.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
.1	1.13	1.15	1.16	1.16	1.16	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
.2	1.28	1.33	1.34	1.35	1.35	1.36	1.36	1.36	1.36	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.38
.3	1.45	1.52	1.55	1.57	1.58	1.58	1.59	1.59	1.59	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.61	1.61	1.61	1.62
.4	1.63	1.75	1.79	1.82	1.83	1.84	1.85	1.86	1.86	1.87	1.87	1.87	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.90
.5	1.83	2.00	2.07	2.11	2.13	2.15	2.16	2.17	2.18	2.19	2.19	2.19	2.20	2.20	2.20	2.21	2.21	2.21	2.21	2.21	2.24
.6	2.04	2.28	2.39	2.44	2.48	2.51	2.52	2.54	2.55	2.56	2.57	2.57	2.58	2.58	2.59	2.59	2.59	2.60	2.60	2.60	2.65
.7	2.27	2.59	2.74	2.83	2.88	2.92	2.95	2.97	2.99	3.00	3.01	3.02	3.03	3.04	3.04	3.05	3.05	3.06	3.06	3.07	3.13
.8	2.50	2.94	3.15	3.27	3.35	3.40	3.44	3.48	3.50	3.52	3.54	3.55	3.57	3.58	3.59	3.59	3.60	3.61	3.61	3.62	3.72
.9	2.75	3.32	3.60	3.77	3.89	3.97	4.03	4.07	4.11	4.14	4.16	4.18	4.20	4.22	4.23	4.24	4.25	4.26	4.27	4.28	4.43
1.0	3.00	3.73	4.12	4.35	4.51	4.62	4.70	4.77	4.82	4.87	4.90	4.93	4.96	4.98	5.00	5.02	5.04	5.05	5.06	5.08	5.30
1.1	3.26	4.18	4.69	5.01	5.22	5.38	5.50	5.59	5.67	5.73	5.78	5.83	5.87	5.90	5.93	5.95	5.98	6.00	6.02	6.03	6.37
1.2	3.52	4.67	5.33	5.75	6.05	6.26	6.43	6.56	6.67	6.76	6.83	6.90	6.95	7.00	7.04	7.08	7.11	7.14	7.17	7.19	7.69
1.3	3.79	5.19	6.03	6.59	6.99	7.29	7.52	7.70	7.85	7.98	8.08	8.17	8.25	8.32	8.38	8.43	8.48	8.52	8.56	8.60	9.33
1.4	4.07	5.75	6.81	7.54	8.07	8.48	8.79	9.05	9.26	9.43	9.58	9.71	9.81	9.92	10.0	10.0	10.1	10.2	10.2	10.3	11.38
1.5	4.34	6.34	7.67	8.62	9.31	9.86	10.2	10.6	10.9	11.1	11.3	11.5	11.6	11.8	11.9	12.0	12.1	12.2	12.3	12.4	13.97
1.6	4.62	6.97	8.62	9.82	10.7	11.4	12.0	12.5	12.8	13.2	13.4	13.7	13.9	14.1	14.3	14.4	14.6	14.7	14.8	14.9	17.25
1.7	4.91	7.65	9.66	11.1	12.3	13.2	14.0	14.6	15.2	15.6	16.0	16.4	16.7	16.9	17.2	17.4	17.6	17.8	17.9	18.1	21.44
1.8	5.20	8.36	10.7	12.6	14.1	15.3	16.4	17.2	17.9	18.6	19.1	19.6	20.0	20.4	20.7	21.0	21.3	21.5	21.7	21.9	26.83
1.9	5.49	9.11	12.0	14.3	16.2	17.8	19.1	20.2	21.2	22.0	22.8	23.4	24.0	24.5	25.0	25.4	25.8	26.1	26.4	26.7	33.82
2.0	5.78	9.89	13.3	16.2	18.6	20.6	22.3	23.8	25.1	26.2	27.3	28.1	28.9	29.6	30.2	30.8	31.3	31.8	32.3	32.7	42.96
2.1	6.07	10.7	14.8	18.3	21.2	23.8	26.1	27.9	29.6	31.2	32.5	33.7	34.8	35.7	36.7	37.4	38.2	39.0	39.4	40.1	54.98
2.2	6.36	11.5	16.3	20.6	24.3	27.4	30.3	32.9	35.1	37.1	39.0	40.4	42.1	43.2	44.6	45.7	46.6	47.5	48.5	49.2	70.93
2.3	6.66	12.5	18.0	23.1	27.6	31.6	35.3	38.6	41.5	44.2	46.6	48.7	50.8	52.4	54.2	55.8	57.1	58.5	59.6	60.7	92.25
2.4	6.96	13.4	19.8	25.8	31.4	36.5	41.1	45.3	49.2	52.4	55.8	58.5	61.5	63.9	66.1	67.9	69.9	71.9	73.6	75.3	120.99
2.5	7.26	14.4	21.7	28.9	35.7	41.9	47.7	53.0	58.1	62.6	66.5	70.4	74.1	77.7	80.3	83.7	85.9	88.2	90.7	93.3	160.04
2.6	7.55	15.4	23.8	32.3	40.4	48.2	55.5	62.2	68.4	74.7	80.3	85.2	89.9	94.2	99.0	102.	106.	110.	112.	115.	213.5
2.7	7.85	16.5	26.1	36.0	45.7	55.1	64.3	73.0	80.9	88.2	96.0	102.	108.	115.	121.	125.	130.	136.	139.	143.	287.4
2.8	8.16	17.6	28.5	39.9	51.6	63.1	74.1	85.2	95.1	105.	115.	124.	132.	139.	148.	155.	160.	168.	174.	180.	390.4
2.9	8.46	18.7	30.9	44.2	58.1	71.9	85.9	100.	112.	125.	137.	148.	160.	171.	180.	191.	199.	207.	216.	226.	535.0
3.0	8.77	19.9	33.7	49.0	65.6	82.3	99.0	116.	132.	148.	166.	180.	195.	207.	221.	237.	249.	262.	269.	284.	739.8
3.1	9.07	21.1	36.5	54.2	73.6	93.3	113.	136.	155.	177.	195.	216.	237.	255.	269.	293.	311.	321.	343.	356.	1,032.
3.2	9.37	22.4	39.4	59.6	82.3	106.	132.	157.	184.	211.	237.	262.	284.	311.	332.	356.	383.	399.	415.	453.	1,454.
3.3	9.67	23.8	42.7	65.7	92.5	121.	150.	184.	216.	249.	284.	311.	343.	383.	415.	433.	475.	499.	525.	554.	2,067.
3.4	9.98	25.1	46.2	72.5	103.	137.	174.	211.	255.	293.	332.	383.	415.	453.	499.	554.	587.	624.	665.	713.	2,967.
3.5	10.2	26.5	49.8	79.6	115.	155.	199.	249.	293.	343.	399.	453.	499.	554.	624.	665.	713.	768.	832.	908.	4,298.
3.6	10.6	27.9	53.3	86.7	127.	174.	226.	284.	343.	415.	475.	554.	624.	713.	768.	832.	908.	999.	999.	1110.	6,284.
3.7	10.9	29.3	57.5	95.2	141.	199.	262.	332.	399.	475.	554.	665.	768.	832.	908.	999.	1110.	1249.	1249.	1428.	9,275.
3.8	11.2	30.8	61.5	103.	157.	221.	293.	383.	475.	587.	665.	768.	908.	999.	1110.	1249.	1428.	1428.	1666.	1666.	13,830.
3.9	11.5	32.4	65.7	112.	174.	249.	343.	433.	554.	665.	832.	908.	1110.	1249.	1428.	1666.	1666.	1999.	2499.	2499.	20,789.
4.0	11.8	34.0	70.4	122.	191.	276.	383.	499.	624.	768.	999.	1110.	1249.	1428.	1666.	1999.	1999.	2499.	2499.	2499.	31,544.
4.1	12.1	35.6	75.3	134.	211.	311.	433.	587.	768.	908.	1110.	1428.	1666.	1999.	1999.	2499.	2499.	3332.	3332.	3332.	48,308.
4.2	12.4	37.3	80.3	146.	237.	356.	499.	665.	832.	1110.	1428.	1666.	1999.	2499.	2499.	3332.	3332.	3332.	4999.	4999.	75,187.
4.3	12.7	39.0	85.2	157.	255.	399.	554.	768.	999.	1249.	1666.	1999.	2499.	2499.	3332.	3332.	4999.	4999.	4999.	4999.	117,646.
4.4	13.0	40.7	90.7	171.	284.	433.	624.	908.	1110.	1428.	[illegible]	2499.	2499.	3332.	3332.	4999.	4999.	4999.	4999.	9999.	185,184.
4.5	13.3	42.5	97.0	184.	311.	475.	713.	999.	1428.	1666.	[illegible]	2499.	3332.	4999.	4999.	4999.	4999.	9999.	9999.	9999.	294,117.
4.6	13.6	44.2	102.	199.	343.	554.	832.	1110.	1666.	1999.	[illegible]	3332.	4999.	4999.	4999.	9999.	9999.	9999.	9999.	9999.	476,189.
4.7	13.9	46.2	108.	211.	369.	587.	908.	1249.	1666.	2499.	[illegible]	3332.	4999.	4999.	9999.	9999.	9999.	9999.	9999.	9999.	769,230.
4.8	14.2	48.0	115.	231.	415.	665.	999.	1428.	1999.	2499.	[illegible]	4999.	4999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	1,249,999.
4.9	14.6	50.0	122.	249.	453.	713.	1110.	1666.	2499.	3332.	[illegible]	4999.	9999.	9999.	9999.	9999.	9999.	9999.	20000.	20000.	1,999,999.
5.0	14.9	51.9	128.	269.	475.	832.	1249.	1999.	2499.	3332.	[illegible]	4999.	9999.	9999.	9999.	9999.	9999.	20000.			3,333,332.
5.1	15.2	53.9	136.	284.	525.	908.	1428.	1999.	3332.	4999.	[illegible]	9999.	9999.	9999.	9999.	9999.	20000.				4,999,999.
5.2	15.5	56.1	143.	302.	587.	999.	1666.	2499.	3332.	4999.	[illegible]	9999.	9999.	9999.	9999.	20000.					9,999,999.
5.3	15.8	58.2	150.	332.	624.	1110.	1666.	2499.	4999.	4999.	[illegible]	9999.	9999.	9999.	20000.						9,999,999.
5.4	16.1	60.3	160.	356.	665.	1249.	1999.	3332.	4999.	4999.	[illegible]	9999.	9999.	20000.							20,000,000.
5.5	16.4	62.3	168.	369.	713.	1249.	1999.	3332.	4999.	9999.	[illegible]	9999.	9999.								
5.6	16.7	64.8	177.	399.	768.	1428.	2499.	3332.	4999.	9999.	[illegible]	9999.	20000.								
5.7	17.0	67.0	184.	433.	832.	1666.	2499.	4999.	9900.	9999.	[illegible]	20000.									
5.8	17.4	69.4	195.	453.	908.	1666.	3332.	4999.	9900.	9999.	[illegible]										
5.9	17.7	71.5	203.	475.	999.	1999.	3332.	4999.	9900.	9999.	[illegible]										
6.0	18.0	74.2	214.	514.	1082.	2074.	3689.	6172.	9900.	15150.	[illegible]										

*Odds should be written as follows: 19 to 1 or 19:1. When it is des[illegible]d the odds that the true value of a constant lies between two points which are on opposite sides of the value of the constant as estimated fro[illegible]le and at the same selected distance (x) from the estimated value, use the following rule: Divide the odds from the above table by 2.0 and subtra[illegible]ample: Odds of 39:1 from the above table become odds of 19:1.

‡The table title gives the meaning of x; S is the standard error of the [illegible] whose significance is being studied.

When studying the significance of a constant, it may be desired to know either of two things. First, one may wish to know the odds or the probability that the true value of the constant *numercially exceeds* a selected value numerically smaller than the estimated value of the constant. Second, one may wish to know the odds or the probability that the true value lies between two values which are obtained by adding any selected value to and subtracting the same value from the estimated value of the constant. It is very important to understand these two concepts and the distinction between them. The writer has found that many persons who use tables of significance, including some authors of recognized books and papers on statistical methods, make statements which indicate a failure to understand the difference between these concepts.

Some illustrations will make clearer a few uses of Table 2. In a test of fertilizing corn, the fertilized corn yielded an average of 9.3 bushels more than the unfertilized corn. The standard error of this mean difference was found to be 3.0 bushels. These facts can be given in the more condensed statement that the mean increase for fertilizer was 9.3±3.0 bushels (standard error).

Let us first find the odds that the true value of the mean *exceeds* selected values.

What are the odds that the true average increase for the fertilizer is between zero and plus infinity, i.e., *exceeds* zero? Zero differs from the mean by 9.3 bushels. Dividing this difference (which is called x) by 3.0 (the standard error) gives 3.1 as the value of t. In Table 2, on the line for $t=3.1$ and in the column for 5 degrees of freedom (df$=5$), it is seen that the odds are 73.6:1 that the true average lies between zero and plus infinity, i.e., that, *under conditions like those of the experiment*, fertilizer is very likely to give *some* increase in the yield of corn. This is an illustration of the general fact that when the value of the mean is taken as x in computing t, Table 2 gives the odds that the *algebraic sign* of the mean is correct.

What are the odds that fertilizer will increase the yield 4.5 bushels or more under similar conditions? The difference between 9.3 bushels (the mean) and 4.5 bushels is 4.8 bushels. This difference (which is now x) divided by 3.0 (the standard error) gives 1.6 as the value of t. In Table 2, on the line for $t=1.6$ and in the column for df$=5$, it is seen that the odds are 10.7:1 that the fertilizer would give an increase in yield of at least 4.5 bushels under the same conditions.

We will now find the odds that the true value is between two values equally distant from and on opposite sides of the mean. This is the second concept mentioned above. For such cases the odds are mentally calculated from the odds in Table 2 by the rule in the footnote to that table.

What are the odds that the true value of the mean lies within the range 9.3±3.0 bushels, i.e., between 6.3 and 12.3 bushels? The t value is 1.0, obtained by dividing 3.0 (the difference, x) by 3.0 (the standard error). Table 2, on the line for $t=1.0$ and in the column for df$=5$, shows odds of 4.51:1. Dividing 4.51 by 2.0 and subtracting 0.5 gives odds of 1.75:1 that the true mean is between 6.3 and 12.3 bushels.

Table 2 may also be used to find the value of t corresponding to any desired odds.

These examples show how the significance of a *mean* can be studied by using Table 2. Table 1 gives, in column A, other constants or variables which can be studied with Table 2. Table 1 also gives correct formulas for calculating the constants and the standard error of each. The formulas in Table 1 are not in their simplest appearing forms, but are in forms for the easiest use in practical calculation.

Student (5)[3] showed that the size of the sample should be considered in determining significance because the estimates of a standard deviation tend to be too small when small samples are used for computing the estimates. The size of sample should be considered not as to the number of cases included but as to the number of degrees of freedom (df). Column C of Table 1 indicates the number of degrees of freedom with which to enter Table 2. When the number of degrees of freedom exceeds 20, the infinity column in Table 2 may be used without danger of arriving at an erroneous conclusion as to the significance of a result, although the odds differ considerably for 20 and for an infinite number of degrees of freedom. Most tables of significance (of odds or of probability) give only one column of significance which is based on an infinite number of degrees of freedom.

The odds in Table 2 were computed from Student's table of probability for t values (6) with corrections of a few obvious errors. The odds for infinity were computed from probabilities carried to seven decimal places. The other values were computed from four decimal places.

If others are to have confidence in the statistical results reported by an investigator, it is essential that he understand the basis for, and the many limitations to, the *logical* use of statistical methods. The ability to use formulas is of secondary importance. It is very important to have at least an elementary knowledge of general statistical methods and, in addition, a thorough knowledge of the use of statistical methods in the field of research in which one is engaged. Only with such knowledge is it possible to make *intelligent* and *correct* use of statistical methods. This knowledge should be acquired from a course or from books on statistical methods and from the literature of one's own field of work. Such information cannot be given properly in a paper of reasonable length. A mere smattering of information is dangerous and is therefore omitted from this paper.

LITERATURE CITED

1. EZEKIAL, MORDECAI. Methods of Correlation Analysis. New York: John Wiley and Sons, Inc. London: Chapman and Hall, Ltd. 1930.
2. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh and London: Oliver and Boyd. Ed. 2, 1928. Ed. 4, 1932.
3. LOVE, H. H. and BRUNSON, A. M. Student's method for interpreting paired experiments. Jour. Amer. Soc. Agron., 16: 60–68. 1924.

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[3] Numbers in parenthesis refer to "Literature Cited", p. 345.

4. SALMON, S. C. The point binomial formula for evaluating agronomic experiments. Jour. Amer. Soc. Agron., 22: 77–81. 1930.
5. STUDENT. The probable error of a mean. Biometrika, 6: 1–21. 1908.
6. ———. New tables for testing the significance of observations. Metron, 5: 105–118. 1925.

NOTES

A PORTABLE SMALL GRAIN THRESHER

The Soils Section of the Michigan Agricultural Experiment Station for several years threshed the grain from the over-state experimental fields with a machine consisting of little more than a cylinder and concave. The machine was carried from place to place on a trailer and was driven by a belt from the rear wheel of a Ford car. A change from the practice of harvesting a few small areas from each plat to that of harvesting a large portion of each plat, leaving only a few border rows to be discarded, necessitated the use of a machine large enough to thresh fairly large amounts of grain and yet small and light enough to be transported readily from one field to another.

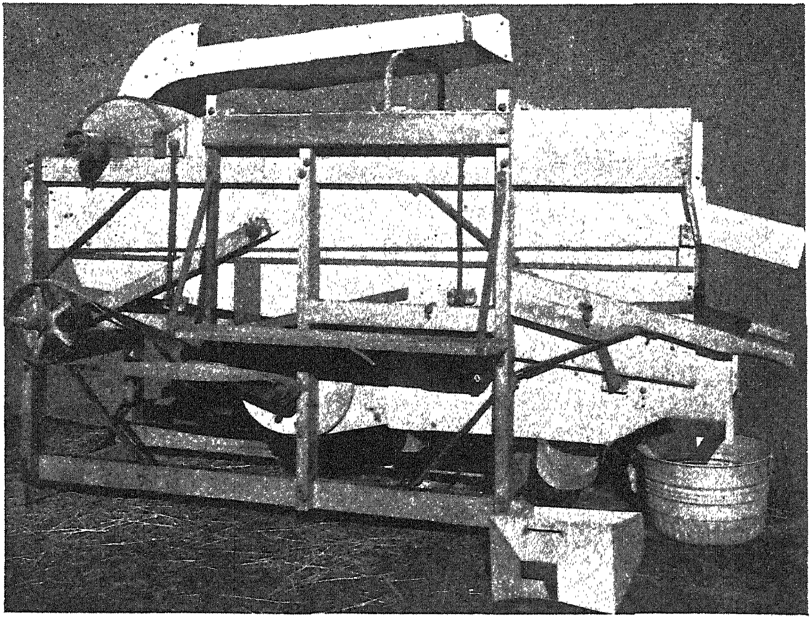

FIG. 1.—Threshing machine in detail.

In the winter of 1927, the writer corresponded with representatives of the experiment stations of several states in an effort to get information which would aid in the purchase or construction of a thresher suitable for our work. The replies indicated that, although there were a large number of different types of threshing machines used at the various stations, there were very few of any one particular type. None of the machines described appeared to meet our requirements.

Many of the investigators were fairly well satisfied with the machines they were using but a few expressed a desire for information concerning a more satisfactory thresher in case one was found. It is to comply with these requests that the following description is published of a medium-sized portable thresher designed and built by the writer.

The bands of the bundles must be cut and the grain fed in by hand at a rate commensurate with the quantity of straw. The entire crop goes through the machine, the straw being separated from the grain and the grain cleaned by mechanisms similar to those in a full-sized separator. The thresher is not suitable for the threshing of grain from plant breeding experiments since the interior is not readily accessible for cleaning and hence mixing of varieties might occur.

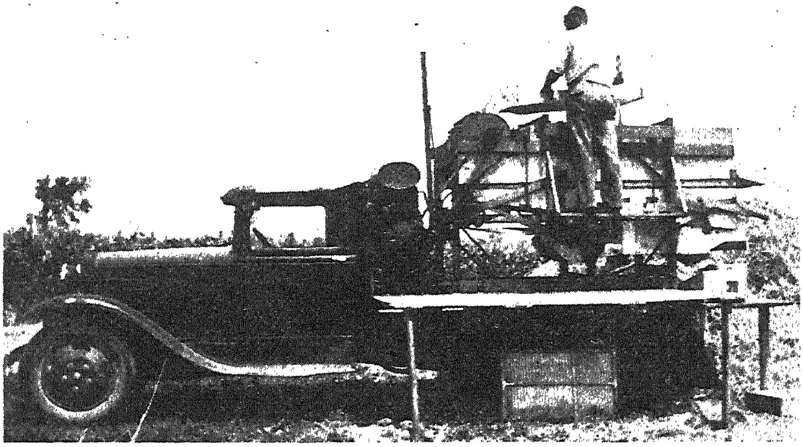

FIG. 2.—Machine mounted and ready for use.

The machine is 8 feet long over all and 2 feet wide, inside measurement. The frame is made of oak 2 x 4's. The base is 6 feet long so that when it is mounted as far back as possible on a Ford truck with a 6 x 8 foot bed there is a space of 2 feet between the thresher and the cab of the truck. This space is sufficient to accomodate a Model T Ford engine which furnishes power for running the thresher. This arrangement with a 30-inch extension on the rear end and one side of the truck bed, as shown in Fig. 2, makes it possible for one to drive into a field and thresh without unloading the machine.

DESCRIPTION OF THE MOTOR

The motor was taken from an ordinary Model T Ford car, mounted in part of its own frame and fitted with a governor which tends to prevent the thresher from slowing down when large quantities of straw are thrown into the cylinder. A 6 x 6 inch roller bearing pulley, made for that purpose, is bolted on the motor at the point where the universal joint and drive shaft are detached. In case of motor trouble in the field it is possible to unload the machine, jack up the rear wheel of the truck and take power from the truck by running a belt from the tire to the pulley on the thresher. This type of power is not steady as the truck is not provided with governor, but it will work in case of necessity.

DESCRIPTION OF THE THRESHER

Cylinder.—The cylinder proper is made of an 8-inch iron pipe 15.5 inches long. The outside of this pipe is about 9 inches in diameter. Each end is fitted with a cast head which is held securely in the end of the pipe by cap screws. That makes a completely closed cylinder, which is advisable since grain cannot get inside and lodge there. There is a 1 3/16 inch hole in the center of each cylinder head through which a shaft of the same size is passed. The shaft and cylinder heads are provided with keyways and are fitted together securely with keys and set screws. The shaft runs in ring oiling pillow block bearings mounted on the frame of the machine. There are two collars on the shaft fitted up close to the bearings and fastened securely with set screws to prevent the cylinder from chucking sidewise on the machine. Six cylinder bars from a 20 x 28 Case thresher, cut to the same length as the cylinder, are placed equi-distant around the cylinder and fastened by means of the teeth. Each of the six bars contains five cylinder teeth which pass through holes drilled in the pipe. The teeth are secured by nuts and lock washers on the inside of the pipe, thus holding the bars securely to it. The cylinder teeth and concave teeth are the same and are of the same size used in the 20 x 28 Case thresher. The total diameter of cylinder, with teeth, is 14 7/8 inches.

Cylinder housing, concaves, and accessories.—The cylinder housing is 15 3/8 inches from top to bottom inside measurements, and 15 7/8 inches from front to back. This is so the whole housing can be moved back or forth on the frame to adjust the distance between the cylinder and the concaves which form a part of the housing. The whole housing rests on two supports across the frame. The front support is of 0.5 by 3 inch strap iron and the back support is an oak 2 x 4 reinforced on top with strap iron. The bottom of this 2 x 4 is cut away in the middle to allow more space for the straw to pass out after it passes the cylinder. The ends of the housing are made of 1.5 inch oak wood around which are properly fitted bands of 3/8 by 1.5 inch strap iron. These oak ends with their strap iron bands are made in two parts so that the top and bottom halves can be unbolted and taken off separately. The wood is lined with sheet metal which extends out and forms part of the feed chute and table. The feet chute is of the same width as the housing, but the table is 24 inches wide, or wide enough to accomodate two large bundles at a time. The ends of the strap iron bands turn out away from the wood in a horizontal position so that those on the top half rest on top of the supports, and those on the bottom half come up under the supports. They are then bolted together securely through the supports. The rear ends of these bands are equipped with slots where the bolts go through and on the front the heavy strap iron support is equipped with slots where it is bolted to the frame so that the whole housing can be moved forward or back to regulate the space between the cylinder and concaves.

The concave bars were made from concaves obtained from the J. I. Case Threshing Machine Company and used by them in their 20 x 28 separator. The concaves come as two rows of teeth set in solid bars with open work between. This open work was cut out so that each row of teeth is in a separate bar. These bars are cut the proper length and bolted on the strap iron bands thus forming a part of the cylinder housing. Each such bar contains eight teeth. Four of these bars are placed on the upper half of the housing between the front support and the feed chute. They are alternated with blank bars 1 inch in width used as spacers. Under the front support, on the lower half of the housing, is a space sufficiently extensive for one concave consisting of two bars with the open work between. On this concave the open work has been covered by welding a piece of strap iron over it. When this concave is installed there are six rows of concave teeth, constituting a total of 48 teeth alternating with each other on consecutive bars. If the operator thinks that the machine so equipped contains too many teeth, he may remove the concave below the support and replace it with a blank, properly shaped from sheet metal at least 1/8 inch thick.

Immediately following the last concave, or the blank, is a "finger grate" designed for use in the Case 20 x 28 separator. This must also be narrowed down to fit the housing and fastened to the oak ends. The finger grate can be made adjustable so that the ends of the fingers can be raised or lowered. It is also possible to bend the fingers to the shape desired. The finger grate allows most of the grain to fall through on the grain pan while the straw is forced over and thrown to the top of the separator from where it falls to the straw rack and is tossed toward the rear. This tossing action shakes the rest of the grain through the rack, allowing it to fall on the grain pan. The remaining portion of the cylinder housing or that part back of the feed chute is covered with heavy sheet metal or thin boiler plate properly shaped.

It will be noted that the top of the machine just back of the cylinder housing curves down gently to a point where it contacts with the cylinder housing support. The top of the machine from this curved part to the rear uprights is provided with removable covers. The curvature in front extends back under these covers in the form of a piece of flexible, adjustable, curved sheet metal, the rear end of which can be raised or lowered to suit the convenience of the operator. As the straw passes off the finger grate it is directed up against the curved portion of the top which, in turn, directs it down on the straw rack. A curtain is hung from the rear end of this curved metal, and another one near the rear of the machine, to prevent grain from snapping out the rear end, which otherwise is open.

Straw rack.—The straw rack is 7 feet long and 23.5 inches wide. It consists of three strips of oak 7/8 inch by 1.5 inch by 7 feet crossed by slats of oak made of 1-inch material cut 3/4 inch on one edge and 1/4 inch on the other edge. These slats are fastened to the strips with screws, with the beveled side down and the wide edge toward the rear so as to aid in pushing the straw to the rear. On top of these slats are three long rakers made of oak strips 7/8 by 23/4 inches with teeth similar to rip saw teeth 4 inches long and 1 1/2 inches high, which also aid in pushing the straw along. The rack is supported by two U-shaped hangers made of 1/2 inch iron rod and suspended from the inner end of the same bolts from which the grain pan is suspended. These hangers are 15 inches long from point of suspension to rack and so arranged that the bottom end is about 8 inches toward the rear of the machine from the top end so that the shaking motion is up and down as well as lengthwise of the machine, the object being to enable straw to be tossed toward the rear.

The straw rack extends to the rear end of the machine but not clear to the front end. The first few slats on the front end, where the grain falls through from the cylinder, are covered with sheet metal. It is inclosed by a sheet metal housing which extends down, and is offset near the bottom so as to extend into the grain pan. The front end of the inclosure is provided with removable parts which allow access to the lower parts of the cylinder housing.

Grain pan.—The grain pan, which is made of sheet metal, is suspended in a manner similar to that used on the straw rack except that the hangers are vertical so that it shakes on a level, with no up and down motion. The front hanger is 23 inches long and U-shaped. The rear hanger is 22 inches long and consists of three pieces, namely, two vertical rods and one cross rod which passes through immediately below the false bottom mentioned below. The bottom of the pan is provided with two strips of wood running lengthwise to prevent grain from running to one side of the pan. It slopes toward the rear, to a point under the rear point of suspension, where the grain runs off on the sieves. There is a false bottom in the rear and beginning about 4 inches from the top of the pan at the rear and sloping toward the front. This catches the grain and chaff that comes through the rear part of the straw rack, carries it forward, and deposits it on the bottom of the pan with the other grain, where it is carried to the sieves. Nearly all of the sheet metal used in the thresher, including that in the grain pan, is 24 gage, reinforced where necessary with strap iron usually not over 1/8 inch in thickness. Light sheet metal was used to keep down the weight and facilitate handling.

Shaking device.—The shaking device consists of a crank shaft and four pitmans made of maple strips 1¼ by 2½ inches. There is one pitman on each side of both the straw rack and the grain pan. The crank shaft is so made that the straw rack pitmans run on 1¼ inch offsets providing 2½ inch throw. The grain pan pitmans run on ½ inch offsets providing 1 inch throw. The offsets are in opposite directions so that the straw rack moves one way while the grain pan moves the other way. The shaft is 1 inch in diameter and runs in common babbit bearings fitted with grease cups. The pitman bearings are of wood. The other ends of the pitmans are attached to the ends of ½ inch gas pipe fastened to the straw rack and grain pan, respectively.

Cleaning devices.—The cleaning devices consist of sieves and fan. The sieves are installed in a unit which is separate from the main part of the machine but attached to it only by four hangers, as shown in Fig. 1, and two connecting rods. The sheet metal in this unit is 20 gage. The hangers are 9 inches long and are made of 3/8 by 1¼ inch strap iron. They hang at an angle rather than vertical so that when the machine is in operation the grain and chaff will be tossed along on the sieves and on the bottom of the unit. The connecting rods are made of 3/8 by 1¼ inch strap iron and run from the rear end of the grain pan down to, and are connected to, the side of the sieve unit as shown just below, and in the shadow of, the brace. The sides of the grain pan are reinforced, both inside and outside, with strap iron running from the rear end of the pan where the connecting rod is attached up to a point near where the wood pitman is connected. The object of this is to strengthen the pan which really acts as a connection between the wood pitmans and the iron connecting rods leading from the pan to the sieve unit. This unit is provided with one adjustable sieve which is used for all grains, and just below this a place is provided for another sieve. This place can be occupied by whatever kind of sieve is necessary for the different kinds of grain threshed. These sieves are put in in such a way that either end can be raised or lowered to suit the convenience of the operator. In addition to the adjustable sieve we have used, so far, only two other sieves. The one used for wheat is made of sheet metal perforated with 15/64 inch cardioid holes. The one used for barley and oats has oblong holes 5/32 x 3/4 inch. The sieves are 20.5 inches wide and 34.5 inches long outside measurements. The first two mentioned were obtained from the J. I. Case Threshing Machine Company and are regular equipment in the upper cleaning shoe of their combine. The other one is homemade. It is probable that either of these sieves could be replaced with other sieves having different sized perforations to facilitate better cleaning of the grain.

A four-blade wood fan on a 1-inch shaft and housed in a sheet metal drum with wood ends is mounted on the supports just in front of the sieves. The fan is 14.5 inches in diameter and 21.5 inches long, and the housing is 15 inches in diameter and 24 inches long, outside measurements. The fan housing is provided with shutters to regulate the intake of air. The outlet for air is so constructed that either the top or bottom can be raised or lowered so that the air current can be directed on the sieves as desired.

The bottom of the sieve unit is corrugated to facilitate the movement of grain toward the rear, and provided with a trough which directs the cleaned grain to one side where it is caught in a convenient container. This trough is made of perforated sheet zinc which is intended to allow soil particles and small weed seeds to fall through and be separated from the grain. Unthreshed heads and threshed grain that go over the sieves are caught in a metal basket at the rear. These constitute the tailings and are thrown back into the cylinder to be run through a second time.

ACCESSORIES

A chute is provided on the rear end to prevent the straw from falling down into the tailings basket after it leaves the straw rack. This is so constructed that it can be turned up and laid on top of the machine when not in use.

There is a convenient foot board on the side of the machine where the man stands to feed it. Handles at the rear are conveniences in moving the machine, as well as supports for the rear end of the sieve unit.

OPERATION

In threshing small grain the cylinder is usually run at a speed of about 1,100 r.p.m. The drive pulley is 4 inches in diameter. A straight belt runs from a 3-inch pulley on the cylinder shaft to a 4-inch pulley on the fan shaft. A crossed belt runs from a 3-inch pulley on the fan shaft to a 12-inch pulley on the crankshaft.

Naturally this machine will not handle a whole bundle at once as a full-sized machine will. However, three men have been able to thresh out as many as 250 large bundles in groups of two and four bundles per sample in less than 7 hours, besides weighing the bundles and the threshed grain. Threshing proceeds much more rapidly when there are more bundles in a sample, so that the pauses between samples are not so numerous. With proper adjustment this machine will clean grain as well as any ordinary thresher making it unnecessary to re-clean it before weighing.—A. G. Weidemann, *Michigan State College, East Lansing, Mich.*

A NEW STIRRER FOR THE HYDROMETER METHOD OF MECHANICAL ANALYSIS OF SOILS

The hydrometer method for making mechanical analysis of soils has apparently met a need and has proved successful, for there are now several hundred scientific and commercial laboratories all over the world using the method.

There is one serious weakness in the apparatus to which attention has been called repeatedly, and that is the paddle on the shaft of the stirring or dispersing machine. This paddle becomes worn on continuous use, especially in sandy and gravelly soils, and when it becomes considerably worn the machine loses most of its dispersing efficiency. The whole success of the hydrometer method depends upon a complete dispersion of the soil, and a complete dispersion can only be obtained when the paddle on the stirring rod is in very good condition.

To eliminate the above weakness in the method, a new stirrer has been devised and adopted. This new stirrer consists of a stirring rod or shaft on which is screwed a solid button or paddle made of case-hardened steel. The paddle lasts longer than the old type and when it becomes worn it can be unscrewed and replaced with a new one without having to change the shaft. The paddle is very inexpensive and it can be changed often so as to maintain the high dispersing efficiency of the method.

It is strongly urged upon those who are now using the hydrometer method to replace the old stirrer with the new one. To effect the change it is only necessary to purchase a new shaft and paddle. The new stirrer is handled by Hamilton Beach Company, Racine, Wisconsin, who have been manufacturing the dispersing motor and cup.—George J. Bouyoucos, *Soils Section, Michigan State College, East Lansing, Mich.*

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LONGEVITY OF AZOTOBACTER IN SOILS TREATED WITH LIME AND SUPERPHOSPHATE[1]

S. C. VANDECAVEYE AND S. ANDERSON[2]

The Azotobacter group, though widely distributed over vast areas of the earth's surface, has been found absent in many soils. In a memoir in which previous work on the non-symbiotic nitrogen-fixing bacteria is reviewed, Winogradsky (11)[3] estimated that approximately 50% of the soils examined are devoid of Azotobacter. The absence of these organisms in the soil has been attributed variously to insufficient amounts of lime, to lack of basicity, to a deficiency of phosphorus, or to a combination of these factors. A careful study of the available literature on the occurrence of Azotobacter in soil made by Gainey (4) showed a close correlation between the absolute reaction of the soil solution and the presence or absence of these bacteria. He came to the conclusion, largely from the results of liquid culture media, that very few acid soils with a pH value below 6.0 contain Azotobacter, whereas soils with reactions of a higher pH value contain these bacteria in most instances. Liquid culture media, however, do not supply favorable conditions for the growth of aerobic bacteria so that results thus obtained are probably not representative of the natural conditions existing in the soil.

Winogradsky (11) pointed out that Azotobacter colonies, naturally fixed and growing on soil particles, are forced to start growth under submerged condition in a more or less thick layer of liquid when introduced into liquid culture media, whereas they are in direct contact with the air, which is natural for them, when introduced into the soil. The characteristic film on liquid media is produced most likely by motile forms rising to the surface where they face strong competition with other organisms. Furthermore, these media become charged with carbonic acid and are almost invariably subjected to butyric acid fermentation so that it is conceivable that the brown film, the sure sign of Azotobacter growth in liquid cultures, can be formed only when the soil carried down in the liquid contains a relatively large number of the specific organisms. Thus, the film indicates only the presence of the organisms without giving the slightest idea of their number or their state of activity in the soil. Gainey (3) was not unmindful of these limitations, for he recognized that little is known as to how many Azotobacter are necessary to initiate the development of a visible film in liquid cultures, and considered it possible that relatively large numbers may be present in a soil and still escape observation by the liquid culture method. Without going further into the voluminous literature on this phase of the subject, it is obvious that much is yet to be learned concerning the activities of Azotobacter in the soil, which is their natural medium, and that a revaluation of the knowledge secured by liquid culture methods should be of interest.

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[1] Contribution from the Division of Agronomy, State College of Washington, Pullman, Wash. Published as Scientific Paper No. 262. Received for publication July 13, 1933.

[2] Professor of Soils and Research Assistant, respectively.

[3] Numbers in parenthesis refer to "Literature Cited," p. 364.

In a search for more effective means of attacking the problem, Winogradsky (11) used silica gel as a basis for culture media. He has shown that a definite quantity of soil evenly scattered on the surface of a silica gel plate impregnated with the proper nutrients permits the development of the Azotobacter colonies under conditions somewhat approaching those obtaining in the soil, and gives a fairly accurate estimate of the Azotobacter population in the soil. Thus, soils that fail to reveal the presence of these bacteria in liquid culture media may give positive results when cultured on silica gel plates. In recent years the occurrence of small numbers of Azotobacter in a large number of soil samples taken at random in western Washington has been revealed by the use of the silica gel plate. As pointed out in a previous publication from this laboratory (9), many of these soils have a hydrogen-ion concentration of pH 5.5 or less, so that the presence of Azotobacter under these adverse conditions, though not necessarily significant from the practical standpoint, is in itself not without interest. Gainey (4) contends that the ability of a soil to support the growth of these organisms can be controlled at will by artificially adjusting the reaction. Niklas, *et al.* (7) believe that soil reaction is not the only limiting factor in the occurrence of Azotobacter in the soil. Soils with a favorable reaction and a high lime content examined by them were devoid of these bacteria. This they attributed to a deficiency of phosphoric acid in the soil. In a recent investigation of the occurrence of Azotobacter in 54 samples of virgin peat soils, many of which were distinctly acid in reaction, Wilson and Wilson (10) were able to induce Azotobacter development in the large majority of these soils, either by additions of mannitol or suitable mixtures of this carbohydrate with one or more inorganic substances. They found no close relationship between the soil reaction and the presence of Azotobacter, and suggested that numerous factors in the soil complex are more important in controlling the activity of these organisms than is the hydrogen-ion concentration.

Although changes in the more complex inherent characteristics of soils cannot be made without difficulty, the reaction of the soil and the available phosphorus content as well, can be controlled in the field, within practical limits, by additions of lime and phosphate fertilizers. The approximate number of Azotobacter colonies or single cells that are active in the soil can be ascertained readily by the use of the silica gel plate. Since the ultimate aim of Azotobacter studies in the soil is essentially to increase nitrogen fixation, incidentally improving soil fertility, it is apparent that to reach this aim comparatively large numbers of these bacteria must be active at intervals at least, and some must be able to survive in the soil indefinitely. Thus, studies with soils devoid of or containing only small numbers of these organisms offer the best chance for success. The work here presented deals with the effect of normal field applications of lime and superphosphate on the longevity of Azotobacter in different soil types, the majority of which are devoid or contain only small numbers of Azotobacter under field conditions.

EXPERIMENTAL PROCEDURE

Representative samples of the surface 8 inches of 24 different types of soil were secured from various points in the state of Washington. Most of these samples were collected during the summer months when the soil was relatively dry and several of them had been stored air-dried in the stockroom before the experiment was started, so that the microbial population in the latter was in all probability severely affected by storage.

All samples were air-dried after they arrived in the laboratory. Soils from the different localities were cultured on silica gel plates to obtain different strains of Azotobacter. Typical Azotobacter colonies were isolated, and to make sure that they were typical Azotobacter, a test was made for their ability to fix atmospheric nitrogen. The test consisted of placing several loopfuls of a suspension of each isolated colony on a silica gel plate previously prepared with Winogradsky's (11) nutrient medium. The inoculated plates were incubated for 1 week at 28° C and a portion of the gel containing bacterial growth was then analyzed for nitrogen, using the micro-method proposed by Doneen (2). Transfers from all the typical Azotobacter colonies that were able to fix appreciable amounts of nitrogen were used as stock cultures for the soil inoculation experiment, without making any further identification of the organisms.

Preliminary to the inoculation experiment, the normal field moisture content, the occurrence of Azotobacter, and the reaction were determined for each soil type.

The optimum field moisture capacity was ascertained by adding water to the air-dried soil until the moisture content and consistency were similar to those in field soils in their best condition for tillage. The difference in weight between the moist and air-dried sample served as a means to calculate the percentage of moisture required for each soil type. This method has been followed regularly in this laboratory and is considered preferable to the arbitrary method of calculating the optimum moisture content of the soil on the basis of one-half or two-thirds saturation.

The occurrence of Azotobacter in the 24 different soils was determined by means of silica gel cultures after the soils had been moistened at optimum field capacity and incubated for a week at room temperature to give the microflora an opportunity to resume its normal functions. The number of Azotobacter in the soils was determined by plating the equivalent of 1 gram of dry soil on duplicate 15-cm silica gel plates.

The pH value of the air-dry soils was determined by the quinhydrone method, using suspensions of 1 part of soil to 5 parts of water. It was again determined on similar soil suspensions at the end of the experiment when the moist soils were used instead of the air-dried soils.

Following the preliminary incubation period, each soil was inoculated with a composite suspension of Azotobacter made up from the various strains previously isolated from the soils. The suspension was such that 15 cc added to 1,000 grams of soil introduced approximately 1,000 Azotobacter per gram of dry soil. The concentration of Azotobacter in the suspension was roughly ascertained in a preliminary manner by turbidity tests and finally by plating on nutrient agar at the time the soils were inoculated.

Four portions, each equivalent to 300 grams of air-dried inoculated soil, were treated as follows:

Portion	Treatment	Amount per acre*
1	Control	
2	0.075 grams superphosphate (16%)	500 lbs.
3	0.60 grams lime ($CaCO_3$)	2 tons
4	0.075 grams superphosphate plus	500 lbs.
	0.60 grams lime	2 tons

*Based on 2,000,000 lbs. dry soil

The treated soils were placed in 250-cc jars, covered loosely with metal covers, and incubated at room temperature which ranged from 20° to 25° C. The weight of each jar was recorded and the moisture content of the soils kept within narrow limits by additions of water when necessary. Azotobacter counts were made periodically, using definite amounts of soil on duplicate 9-cm silica gel plates impregnated with Winogradsky's (11) nutrient solution. The quantities of soil used ranged from 25 mgs of dry soil per plate for the first platings when the numbers of bacteria were high to 500 mgs of dry soil in the last platings when the numbers of bacteria were generally low.

EXPERIMENTAL RESULTS

Successful inoculation of soils with Azotobacter can hardly be hoped for unless the organisms introduced can survive in relatively large numbers. Obviously survival of the organisms cannot be expected unless conditions in the soil are suitable for their development. Owing to the wide natural distribution of the Azotobacter group, it is logical that there should be variation in strains and therefore in adaptation of different strains to different environmental conditions. To avoid the possible effects that might result from the use of a single species or strain, as many of the typical Azotobacter colonies as were isolated from the 24 different soil types and were capable of fixing appreciable amounts of atmospheric nitrogen were mixed together for inoculation of the soil samples. Since it is recognized that nitrogen-fixing power is not exclusively a function of Azotobacter, the adaptability of the soils for the development of these organisms cannot be accurately estimated by the total amount of nitrogen fixed, but can be more accurately measured by determining the ability of Azotobacter to survive in the soil. Therefore, actual counts of Azotobacter colonies as they developed on soil particles spread on silica gel plates impregnated with Winogradsky's nutrient medium were made; first, 2 months after inoculation with approximately 1,000 organisms of mixed strains per gram of dry soil; second, 4 months after inoculation; and finally 14 months after inoculation. The results which are average counts from convenient but definite quantities of soil on silica gel in 9-cm petri dishes are given in Table 1. For convenience of interpretation, the 24 different types of soil have been arranged in two main groups, one group consisting of soils formed under the humid climate of western Washington, and the other of soils formed under the arid and semiarid climates of central and eastern Washington. The number of Azotobacter present in the soils as received from the field and the pH values of air-dried samples are given in columns one and two, respectively.

Two points are of interest. First, it is noted that, with one exception, Azotobacter was present in all soils that had not been kept in storage. This was true irrespective of soil reaction. The second point is that in 21 of 24 cases the hydrogen-ion concentration of the air-dried soils was less than that of the same soils after they had been kept at normal field moisture capacity for 14 months. The pH value of the moist soil is given in column 6. A difference in pH value between the air-dried and moist samples of the same soil is not unusual, and the change in reaction may be either a decrease or an increase in hydrogen-ion concentration, the result apparently depending upon the nature of the soil.

That there is a change in reaction in many cases is clearly demonstrated in the numerous data presented in a recent publication by Bailey (1). Inasmuch as microbial life is active only in the presence of an adequate moisture supply, the reaction of the moist soil rather than that of the air-dried soil normally affects the activity of Azotobacter in the soil. Keeping this in mind, it is noted that all the soils from the humid section of western Washington here used are acid in reaction and that 10 of them, or 55%, have a pH value of 5.5 or below. Of these 10 soils, 5 had been stored air-dried for several months so that Azotobacter life, if present at all under field conditions, may have been destroyed during storage. It is significant that Azotobacter was present in four of the five remaining soils that had a pH value of 5.5 or less. If Azotobacter is able to survive, even though the number may be small, in soils considerably more acid than the pH value of 6.0, the maximum hydrogen-ion concentration set by Gainey (5), and if soil reaction is the major factor controlling the existence of Azotobacter as pointed out by the same author, a change in reaction from additions of lime such as was brought about in many of the soils here used should make them much more suitable for the survival of these organisms. The data show that this was

TABLE 1.—*Number of Azotobacter in variously treated soils and soil reaction at the beginning and at the end of the experiment.**

Soil	Azotobacter per gram of original soil	pH of original air-dry soil	Azotobacter per gram of dry soil at periods indicated after inoculation and pH value of the moist soils at the conclusion of the experiment															
			Untreated			pH 14 mo.	Superphosphate			pH 14 mo.	Lime			pH 14 mo.	Lime and superphosphate			pH 14 mo.
			2 mo.	4 mo.	14 mo.		2 mo.	4 mo.	14 mo.		2 mo.	4 mo.	14 mo.		2 mo.	4 mo.	14 mo.	
							Western Washington											
Everett sandy loam	31	6.8	570	5	1	6.1	480	00	00	6.4	650	22	36	6.9	500	175	42	6.9
Everett loam	1	6.4	120	10	00	6.0	150	25	00	5.9	450	350	7	6.5	1,100	442	7	6.6
Everett gravelly loam†	1	6.1	70	00	2	5.2	130	20	1	5.8	3,700	505	87	6.4	490	265	32	6.4
Bellingham silt loam	1	6.3	2,000	2	00	5.9	40	22	00	5.9	420	245	45	6.6	280	170	59	6.7
Whatcom silt loam	1	6.5	960	110	3	5.8	2,300	172	1	5.8	800	260	4	6.2	1,400	310	2	6.2
Puget sandy loam	45	5.6	00	00	1	5.0	100	00	1	4.9	390	270	00	5.6	750	405	00	5.8
Puget silt loam†	00	5.9	00	5	6	4.9	620	10	00	5.4	1,500	1,270	4	6.0	500	490	20	6.1
Puget silt loam	6	6.1	2,900	112	3	5.4	1,940	225	3	5.7	1,000	600	22	6.1	1,000	1,050	18	6.2
Puget silty clay	00	5.8	00	00	00	4.7	20	5	1	4.7	00	1	5	4.9	00	00	00	4.9
Olympic clay	1	5.9	140	15	2	5.6	160	165	00	5.5	700	15	53	6.0	1,440	80	59	6.0
Olympic loam†	00	6.6	1,860	125	20	5.9	850	105	9	5.8	640	150	39	6.4	920	175	21	6.5
Hesson silt loam	3	5.8	500	00	3	5.1	40	00	2	5.1	230	2	2	5.6	170	6	2	5.5
Felida silt loam†	5	6.1	480	95	00	5.8	405	60	00	5.8	1,100	550	45	6.2	2,550	205	17	6.4
Felida fine sandy loam	1	5.3	100	00	00	5.2	00	00	3	5.3	490	40	00	6.1	450	40	4	6.3
Salkum clay loam†	00	6.0	500	00	00	5.4	1,560	10	2	5.3	1,120	65	2	6.0	2,120	25	7	6.0
Melbourne silt loam†	00	5.7	00	1	00	4.9	00	40	1	4.8	40	15	00	5.4	00	11	00	5.3
Lauren fine sandy loam†	00	5.8	100	00	2	5.6	520	00	2	5.5	140	130	00	6.0	100	50	3	6.0
Chehalis clay loam†	00	5.4	70	5	1	5.3	290	20	00	5.6	250	40	00	5.9	340	40	3	5.9
							Central and Eastern Washington											
Walla Walla silt loam	34	7.7	4,500	300	750	7.7	5,000	225	675	7.8	650	1,050	985	7.9	1,000	100	825	7.8
Ephrata fine sandy loam	13	6.9	500	250	17	6.4	2,000	190	5	6.5	2,450	750	950	7.7	2,400	700	815	7.4
Ephrata sandy loam	24	7.6	350	170	260	7.7	875	150	405	7.7	865	315	395	8.1	860	540	390	8.0
Ritzville silt loam	1	7.0	2,300	850	103	7.2	1,450	680	99	7.3	160	365	125	8.1	390	285	94	8.0
Palouse silt loam†	2	7.2	200	45	24	6.8	440	110	65	6.9	1,240	175	1,005	7.5	1,420	90	1,040	7.5
Yakima sandy loam	6	7.2	300	20	52	6.9	250	35	77	6.9	1,000	350	118	8.0	3,000	195	256	7.8

*Experiment started April 15, 1930, and concluded June 15, 1931.

†Soils kept in storage for several months before the experiment was started.

actually the case. With few exceptions Azotobacter failed to survive in soils that had a pH value of 6.0 or less and had not received lime. On the other hand, when lime was added at the rate of 2 tons per acre, and when such additions caused an increase in pH value to 6.0 or more, Azotobacter, though relatively small in number, was still present in all but one soil after 14 months' incubation. Furthermore, it is apparent that, in general, the number of organisms surviving was greater the lower the hydrogen-ion concentration of the soil. Thus, the soils with a final pH value of 6.5 or more seemed to be better able to support Azotobacter growth than the soils with pH values ranging between 6.0 and 6.5. It must be noted, however, that in all cases, irrespective of soil treatment, the number of Azotobacter surviving in the acid soils of western Washington was much smaller than the number surviving in the distinctly alkaline soils from the arid and semiarid sections of central and eastern Washington.

Not much is known regarding the actual number of Azotobacter ordinarily present in field soils that are considered favorable for the development of these bacteria. Winogradsky (11) found a great variation in numbers in soils in which the aerobic nitrogen-fixing bacteria were thought to be active. Samples containing only a few dozen Azotobacter colonies per gram of dry soil were not rare, and occasionally supposedly active soils were found to contain only a few or even a single colony per gram.

Data obtained in this laboratory show that there is a considerable fluctuation in numbers of Azotobacter in the same soil at different times of the year. The results of periodic determinations on samples prepared by mixing 10 auger borings of soil 10 inches deep taken uniformly on summer-fallowed field plats considered ideal for the growth of these bacteria, are given in Table 2. The figures represent average counts on duplicate 15-cm silica gel plates on which the equivalent of 0.5 gram of dry soil was evenly scattered. It is noted that a maximum of approximately 400 Azotobacter colonies per gram of soil were present in October and that there must have been nearly a total absence of these bacteria during the months of June, July, and August. This fluctuation in numbers occurred in spite of the fact that the soil moisture at the depth the samples were taken was at normal field capacity during the summer months. Although it is logical to expect that any particular group of organisms in a given soil should soon reach a more or less constant level as to numbers and vigor, the level depending upon environment and competition with other organisms, it is conceivable that changes in the available food supply and in temperature may cause rather abrupt fluctuations in this level. It should not be expected that appreciable quantities of nitrogen will be fixed by Azotobacter in the field unless relatively large numbers are present. Data intended for a subsequent publication show that in the same soil type as that used for the periodic determinations of Azotobacter relatively large quantities of atmospheric nitrogen were fixed only when the Azotobacter population reached several thousand colonies per gram of dry soil, and no measurable amounts of nitrogen were fixed when this number was only a few hundred. The ability of a soil to support these bacteria permanently is not necessarily an indication that their activity will be sufficient to fix measurable quantities of atmospheric nitrogen, but merely gives assurance of potential fixation of atmospheric nitrogen by these organisms. A practical soil management procedure that will change a soil poorly adapted for the growth of Azotobacter to one providing a desirable medium for these organisms, therefore, is an important step forward.

TABLE 2.—*Seasonal trend in numbers of Azotobacter in fallow Palouse silt loam.**

Date	Azotobacter colonies per gram of dry soil from field plats treated as follows†		
	Untreated	Straw + $NaNO_3$	Straw + $(NH_4)_2SO_4$
March 3	25	45	15
March 19	85	120	60
April 9	125	390	110
April 29	110	360	200
May 18	40	90	20
June 8	None	10	None
June 29	None	None	None
July 25	None	None	None
Aug. 6	None	None	None
Sept. 5	100	150	70
Sept. 17	130	160	90
Oct. 2	290	260	110
Oct. 28	320	360	220
Nov. 27	110	120	90

*The authors are indebted to M. C. Allen for the data in this table.

†The plats had been in existence for 9 years and had received the fertilizer treatments in alternate years in the spring of the summer-fallow year. $NaNO_3$ was used at the rate of 370 pounds per acre, $(NH_4)_2SO_4$ at the rate of 285 pounds per acre, and straw at the rate of 2,700 pounds per acre.

The results in Table 1 indicate that moderate applications of lime to many of the acid soils in western Washington may be sufficient to lower the hydrogen-ion concentration materially, thereby making these soils a more suitable habitat for Azotobacter. Thus, the findings of Gainey (5) that acid soils in which the reaction has been changed to a pH value of 6.0 or above by additions of lime are better able to sustain Azotobacter than the unlimed acid soils, are largely supported in so far as this experiment was carried out. Whether this change in soil reaction is in itself adequate to support sufficient numbers of Azotobacter permanently to make fixation of measurable quantities of atmospheric nitrogen possible under field conditions, the ultimate aim to be attained, remains to be determined by further investigation.

As noted previously in this paper, Niklas, *et al.* (7) pointed out the need of an adequate supply of available phosphorus as well as a suitable reaction for the support of Azotobacter in the soil. Additions of superphosphate at the rate of 500 pounds per acre, either alone or in combination with lime, failed to show any significant effect upon the longevity of Azotobacter, although it is known that crops on many of these soils respond favorably to applications of phosphate fertilizers. This may be explained possibly by the fact that the Azotobacter group, though very responsive to phosphorus, is at the same time resistant to adverse phosphorus conditions in the soil, as emphasized by Winogradsky (12) who found notable growth of these bacteria in media containing only unmeasurable traces of phosphorus. To ascertain further the adequacy of available phosphorus for the normal activity of Azotobacter in these soils, several of the samples previously used in the inoculation experiment and treated respectively with lime, superphosphate, and lime in combination with superphosphate were subjected to Sackett and Stewart's (8) soil plaque test as modified by Halversen (6), after first being inoculated with a suspension of Azotobacter.

The modification consists in moistening the soil in the plaques with a solution of 1.5% agar after the prescribed nutrient salts are added. Sufficient agar solution at a temperature of 45° C is quickly added to give the soil a pasty consistency, so that it will settle evenly, leaving a smooth surface when the agar solidifies. The plaques receiving lime were treated with calcium carbonate at the rate of 2.5 grams per 300 grams of soil. The advantages of this modification are that an adequate moisture supply is more easily maintained during incubation of the plaques and that bothersome fungus growth so often encountered in acid soils is largely eliminated. Furthermore, Azotobacter growth is more distinct and more easily recognized. The results of the modified plaque test are given in Table 3.

The data show that in 8 of the 11 soils tested Azotobacter growth did not respond materially to the addition of phosphate salts to soils previously treated with superphosphate at the rate of 500 pounds per acre. When calcium carbonate was added to plaques of soils previously treated with superphosphate, a favorable response was obtained in only 4 of the 11 soils tested, and when a combination of phosphate salts and calcium carbonate was added, Azotobacter growth was markedly stimulated in 6 of the 11 soils tested. The greatest and most uniform stimulation in Azotobacter growth was obtained on the plaques treated with calcium carbonate in combination with phosphate and potash salts. This was especially noticeable on the plaques made of the soils previously treated with lime in combination with superphosphate. Thus, neither a change in reaction alone, nor the addition of phosphorus seemed to provide the best conditions for Azotobacter growth, but an abundant supply of potassium in addition to phosphorus and calcium seemed to be necessary.

The results of the plaque test give evidence that the soils previously treated with superphosphate were, with possibly a few exceptions, sufficiently well supplied with available phosphorus to support a thrifty growth of Azotobacter, as the majority of the samples tested failed to give any better response from additional phosphate salts than those soils from eastern Washington (Ephrata sandy loam and Palouse silt loam) which are known to support a vigorous growth of these bacteria in the field, and at the same time proved to be able to maintain the largest numbers of Azotobacter

TABLE 3.—*Azotobacter growth on soil plaques prepared from different soil types previously treated with lime and superphosphate.**

Soil type	Previous soil treatment	pH	Growth on soil plaques treated as indicated‡					
			Check	P	Ca	PCa	PK	PKCa
Everett gravelly loam†	Superphosphate	5.8	0	X	0	0	0	3
	Lime	6.4	0	0	0	X	3	2
	Lime+superphate	6.4	0	3	X	3	4	4
Everett sandy loam	Superphosphate	6.4	0	X	2	2	3	3
	Lime	6.9	2	1	1	2	3	3
	Lime+superphosphate	6.9	2	3	2	3	4	4
Whatcom silt loam	Superphosphate	5.8	X	3	2	4	0	3
	Lime	6.2	1	4	4	3	3	4
	Lime+superphosphate	6.2	X	2	2	3	3	3
Bellingham silt loam	Superphosphate	5.9	0	0	1	3	0	3
	Lime	6.6	1	3	2	4	4	3
	Lime+superphosphate	6.7	2	3	2	4	4	4
Puget silt loam†	Superphosphate	5.4	0	0	X		0	3
	Lime	6.0	1	2	X	3	2	4
	Lime+superphosphate	6.1	0	0	X	X	0	2
Puget silty clay	Superphosphate	4.7	0	0	0	1	0	0
	Lime	4.9	0	0	0	X	0	X
	Lime+superphosphate	4.9	X	2	1	4	1	4
Salkum clay loam†	Superphosphate	5.3	0	2	X	3	2	3
	Lime	6.0	0	1	X	3	1	3
	Lime+superphosphate	6.0	0	2	X	2	1	2
Lauren fine sandy loam†	Superphosphate	5.5	0	1	1	2	0	2
	Lime	6.0	0	2	1	2	1	2
	Lime+superphosphate	6.0	0	2	1	2	1	2
Chehalis clay loam†	Superphosphate	5.6	—	—	—	—	—	—
	Lime	5.9	—	—	—	X	—	—
	Lime+superphosphate	5.9	—	—	—	X	—	—
Ephrata sandy loam	Superphosphate	7.7	4	1	3	2	3	3
	Lime	8.1	1	1	1	2	4	4
	Lime+superphosphate	8.0						
Palouse silt loam†	Superphosphate	6.9	0	X	1	1	1	X
	Lime	7.5	3	2	3	2	1	2
	Lime+superphosphate	7.5	3	2	3	3	2	1

*The authors are indebted to L. Bond for the data in this table.

†Soils kept in storage for several months before the experiment was started.

‡0=no growth; X=trace; 1=slight growth; 2=moderate growth; 3=good growth; 4=excellent growth; —=fungus growth.

in the inoculation experiment, as shown by the data in Table 1. It is evident also that vigorous Azotobacter colony development on soil plaques can be expected only when excessive quantities of mineral as well as organic nutrients are available.

Seemingly the solution of the problem of successful inoculation of field soils with Azotobacter cannot be expected by merely adjusting the soil reaction. A suitable soil medium with an adequate supply of appropriate carbohydrates and of available mineral nutrients, especially phosphorus, calcium, and potassium, seems to be necessary if the ultimate aim is to support not only a permanent Azotobacter population in the soil but an active population capable of fixing measurable quantities of atmospheric nitrogen as well.

SUMMARY

Representative samples of 24 different soil types, including soils formed under humid, semiarid, and arid climates, were used to study the effect of normal field applications of lime and superphosphate on the longevity of Azotobacter.

Preliminary examination of the samples revealed that 15 of the 16 soils received direct from the field and not kept in storage contained active Azotobacter, but in the majority of cases the number of these bacteria present was small. This was true regardless of the soil reaction, which in nine samples represented pH values ranging between 4.7 and 6.0.

Untreated as well as superphosphate-treated soils having a pH value of 6.0 or less failed to support appreciable Azotobacter development following inoculation with a mixed culture of different strains of these bacteria which introduced approximately 1,000 organisms per gram of dry soil. The same soils were better able to support Azotobacter growth when lime had been added either alone or in combination with superphosphate, as they still contained appreciable numbers of these bacteria 14 months after inoculation.

Data are presented to show that under field conditions there is a great fluctuation in numbers of Azotobacter during different times of the year in a soil considered well adapted for the development of these bacteria.

Azotobacter development was not appreciably benefited from normal field applications of superphosphate applied either alone or in combination with lime, nor did it respond materially to further additions of phosphate salts as used in the soil plaque test.

The results of the experiments indicate that although applications of lime sufficient to change the reaction of acid soils to a pH value above 6.0 may promote the longevity of Azotobacter, other factors than reaction must be considered before successful inoculation can be expected. It seems that a suitable soil medium in addition to an adequate supply of appropriate carbohydrates and essential mineral nutrients is necessary to establish a sufficiently permanent and active Azotobacter flora in the soil to fix measurable quantities of atmospheric nitrogen under field conditions.

LITERATURE CITED

1. BAILEY, E. H. The effect of air drying on the hydrogen-ion concentration of the soils of the United States and Canada. U. S. D. A. Tech. Bul. 291. 1932.
2. DONEEN, L. D. A micro-method for nitrogen in plant material. Plant Physiol., 4 : 717–720. 1932.
3. GAINEY, P. L. Influence of the absolute reaction of a soil upon its Azotobacter flora and nitrogen fixing ability. Jour. Agr. Res., 24 : 907–938. 1923.
4. ————. The occurrence of Azotobacter in soil. Proc. 1st Int. Cong. Soil Sci., Commis. III, 3 : 107–117. 1927.
5. ————. A study of factors influencing inoculation experiments with Azotobacter. Kan. Agr. Exp. Sta. Tech. Bul. 26. 1930.
6. HALVERSEN, W. V. University of Idaho. Private correspondence. 1932.
7. NIKLAS, H., POSCHENRIEDER, H., and HOCK, A. Über die Verbreitung des Azotobacter in den Boden Bayerns unter Berücksichtigung der Bodenreaction des Kalk und Phosphorsaüvegehaltes derselben. Centblt. Bakt., 2 Abt., 66 : 16–28. 1926.
8. SACKETT, W. G., and STEWART, L. C. A bacteriological method for determining mineral soil deficiencies by use of the soil plaque. Colo. Agr. Exp. Sta. Bul. 375. 1931.
9. VANDECAVEYE, S. C. Effects of stable manure and certain fertilizers on the microbiological activities in virgin peat. Soil Science, 33 : 279–299. 1932.
10. WILSON, J. K., and WILSON, B. D. The occurrence of Azotobacter in peat soils of New York. Cornell Univer. Agr. Exp. Sta. Mem. 148 : 1–19. 1933.
11. WINOGRADSKY, S. Études sur la microbiologie du sol: II Sur les microbes fixateurs d'azote. Ann. Inst. Pasteur, 40 : 455–520. 1926.
12. ————. Sur l'application agronomique d'ume épreuve microbiologique. Compt. Rend. Acad. Sci. (Paris), 187 : 161–165. 1928.

PHYSIOLOGICAL ACIDITY AND ALKALINITY OF INORGANIC NITROGENOUS COMPOUNDS IN SOLUTION CULTURES[1]

JOHN P. CONRAD[2]

Pantanelli (13)[3] in 1915 explained that physiological alkalinity results from the OH ions left in the medium through the dissociation of water when H ions are absorbed by the plant with the NO_3 ions and that physiological acidity is due to the H ions correspondingly left behind when OH ions are absorbed with the NH_4 ions. From the point of view of the residual effect of concentrated nitrogen fertilizers on permanent soil acidity, Allison (1) submitted evidence which substantially agrees with Pantanelli's theories. The writer elsewhere (3) advanced the processes of protein formation and that of similar compounds as the fundamental causes of these phenomena. These processes may be summarized in the following reactions for physiological alkalinity (A) and physiological acidity (B):

$$a\ H_2CO_3 + b\ HNO_3 + c\ H_2SO_4 + d\ H_3PO_4 = \text{protein} + m\ H_2O + n\ O_2 \qquad \text{(A)}$$

$$a\ H_2CO_3 + b\ NH_4OH + c\ H_2SO_4 + d\ H_3PO_4 = \text{protein} + m'\ H_2O + n'\ O_2 \qquad \text{(B)}^4$$

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[1] Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication July 19, 1933.

[2] Associate Agronomist.

[3] Numbers in parenthesis refer to "Literature Cited," p. 371.

[4] The steps by which proteins are formed from ammonium compounds as postulated by Engel (5) agree with the over-all equation (B).

These equations express the over-all reactions for proteins formed by higher plants from their inorganic environment.

Disregarding H_2CO_3 as coming from the air in the form of CO_2 and considering H_2SO_4 and H_3PO_4 of only minor importance because of the small amounts involved, we notice that the form of nitrogen is the greatly dominant factor in the change of titrable acidity in the formation of proteins by plants. Pure proteins, though generally slightly acid in reaction, may be considered essentially neutral when compared with the alkalinity or acidity of NH_4OH or HNO_3 equivalent, respectively, to the nitrogen in the proteins. Such profound changes in titrable acidity taking place in protein formation undoubtedly would be reflected in absorption phenomena. Qualitatively this is true, but quantitatively not so far as solution culture work is concerned. This study was undertaken to investigate some of the factors which might cause a lack of quantitative agreement (determined largely from the standpoint of absorption) with the reactions given above.

PROCEDURE

From a study of previous work and the writer's own preliminary experiments, it was evident that lack of quantitative agreement between absorption experiments and the theories advanced (3) might be found, in part at least, in the following:

1. All of the NO_3 or NH_4 ions were not absorbed from the culture solutions.
2. The conditions of conducting the experiments did not allow sufficient time for absorbed NO_3 or NH_4 ions to be converted into organic forms.
3. If absorption takes place as HNO_3 and NH_4OH sufficient account was not taken of the absorption of the resulting HCO_3 and H ions, respectively, left in the culture solution.

The experimental procedure adopted to take care of these factors and the other details of the experiments are given below.

To develop the plants to the proper size, culture solutions were used in the following order after germination of the seeds: (a) Complete nutrient solution with nitrogen supplied as NH_4NO_3, plants remaining in the solution until of proper size; and (b) the same solution lacking the NH_4NO_3, plants remained at least 2 to 4 days.

The plants were then tested in single salt solutions in comparison groups as shown in Tables 1 and 2. Comparisons were made between solutions of the nitrogen compound in question and the same compound which would result if either HNO_3 or NH_4OH were removed and sufficient CO_2 added to change any OH ions to HCO_3 ions. Each test was generally in triplicate, but in a few cases only in duplicate. Plants were grown in tumblers with 180 cc of solution per culture, and distilled water was added from time to time to compensate for transpiration and evaporation. The concentrations expressed are on the basis of the final dilution to 250 cc, the extra 70 cc being allowed for washing at the time of changing plants from solution to solution. Solutions were calculated to contain 4 milligram-atoms of N per liter when finally diluted to 250 cc. After the completion of the cultural part of the experiments reported in Table 2, the plants were dried in the oven at about 70° C, ground with a Wiley motor-driven grinder to pass a 40-mesh sieve, and the pH of a water suspension determined with the quinhydrone electrode.

TABLE 1.—*The effects of sorghum seedlings upon single salt solutions in various preliminary comparison trials.*

Chemical	Before plant absorption			After plant absorption		
	HCO_3^-,* M.E.	H^+, M.E.	pH†	HCO_3^-, M.E.	H^+ M.E.	pH†
$(NH_4)_2SO_4$	0.04		5.25		0.53	3.14
H_2SO_4	—	4.58	2.19	—	0.52	3.17
KNO_3	0.10	—	6.06	0.80	—	7.02
$KHCO_3$	5.00	—	7.53	0.78	—	7.09
$NaNO_3$	0.09	—	5.77	1.27	—	7.04
$NaHCO_3$	5.00	—	7.63	1.45	—	7.05

*Methyl orange titration.
†Quinhydrone.

RESULTS

The results of the preliminary tests with sorghum seedlings are given in Table 1 and the more extensive ones with maize seedlings in Table 2. With the sorghum plants, as shown in Table 1, the differences between the residual liquids of the various comparisons used were almost negligible. With the maize plants (cf. Table 2) the corresponding differences were somewhat greater.

With the comparison group HNO_3, NH_4NO_3, NH_4HCO_3, and H_2O, the residual liquids, after the maize plants had absorbed all of the NH_4 and NO_3 ions, were practically the same in composition except for the pH readings on the residual liquid from the HNO_3 solution. The comparatively long time (several months) in which the diluted HNO_3 had been allowed to stand in the bottle before use might have allowed sufficient interaction with the glass to form an appreciable amount of sodium or other nitrates in the acid solution. The "physiological alkalinity" of the nitrates thus formed would explain, at least in part, the higher pH values found. There has been no opportunity to re-test this comparison group since then.

The amounts of acids and bases absorbed by the plants were reflected in the pH values of aqueous suspensions of the ground, dried plant materials (cf. last column of Table 2). These values were naturally divided into three groups, as follows: (a) Plants grown in acid and physiologically acid solutions produced the lowest pH values, (b) those grown in neutral and physiologically neutral (including HNO_3 and NH_4HCO_3) solutions produced intermediate ones, and (c) those grown in alkaline and physiologically alkaline solutions produced the highest values. There was a greater difference between groups (b) and (c) than between (a) and (b). With the use of $(NH_4)_2SO_4$, Hoagland (6) obtained lower pH values in the plant juices. With $NaNO_3$ and KNO_3 he secured slightly higher pH values than normal.

TABLE 2.—*The effects of maize seedlings upon single salt solutions in various comparison groups.*

Solutions		Cultures per treatment	Plants per culture	Before plant absorption			After plant absorption			Aqueous suspensions ground dried plant material pH*
No.	Chemical			HCO_3^-, M.E.	H^+, M.E.	pH*	HCO_3^-, M.E.	H^+, M.E.	pH*	
a	$(NH_4)_2SO_4$	2	16	0.10		5.76		2.34	2.66	5.20
b	H_2SO_4	2	16	—	3.61	2.49		2.15	2.74	5.12
c	NH_4Cl	3	16	0.14		5.70		1.83	2.80	5.22
d	HCl	3	16	—	3.59	2.43		1.57	2.97	5.25
e	$NaNH_4HPO_4$	3	14	4.14	—	7.51	0.03	—	4.19	—
f	NaH_2PO_4	3	14	0.18	—	4.32	0.05	—	4.33	—
g	HNO_3	3	16	—	3.57	2.41	0.18	—	5.95	5.31
h	NH_4NO_3	3	16	0.14	—	5.60	0.14	—	5.20	5.27
i	NH_4HCO_3	3	16	3.96	—	7.47	0.11	—	5.27	5.25
j	H_2O	3	16	0.16	—	5.87	0.12	—	5.20	5.27
k	KNO_3	2	16	0.18	—	5.89	0.30	—	6.54	5.67
l	$KHCO_3$	2	16	4.14	—	7.63	1.07	—	7.15	5.57
m	$NaNO_3$	3	16	0.14	—	5.86	1.50	—	7.18	5.62
n	$NaHCO_3$	3	16	4.14	—	7.51	2.16	—	7.28	5.58
o	$Ca(NO_3)_2$	2	14	0.14	—	5.81	2.83	—	7.48	5.40
p	$Mg(NO_3)_2$	2	14	0.20	—	5.91	2.20	—	7.42	5.58

*Quinhydrone.

According to equation (A) the acidity of HNO_3 should completely disappear in the transformation to protein. To test this out a comparison can be made between plants supplied HNO_3 and others supplied only H_2O (cf. Table 2, g, j). There was but little difference between the residual titrable acidities and between the pH values of the ground plant materials. No acidity remained in the residual culture liquid and there was no evidence of it in the plant material. In the case of the cultures in H_2SO_4 and HCl solution (cf. Table 2, b, d), it should be noticed that after plant absorption for approximately the same length of time acidity was evident both in the residual culture liquids and in the respective plants. It is worthwhile noting here that H ions must have been absorbed equivalently to the NO_3, SO_4, and Cl ions (c. f. Table 2, g, b, and d, respectively) absorbed because they were the only cations in the solution. To the list of anions must be added OH ions. But if these were absorbed with an equivalent amount of H ions, we would simply have the absorption of H_2O. The absorption then must have been that of HNO_3, of H_2SO_4, and of HCl in each case.

According to equation (B) the alkalinity of NH_4OH should completely disappear in the transformations to proteins. From the data secured in these experiments (cf. Table 2, i, j), the NH_4OH[5] has entered into the formation of proteins or similar substances with the complete removal of the titrable alkalinity from the residual liquids and the lack of any evidence of it in the plant as the pH of the plant material was but little different from that of the plants grown in H_2O. In the case of cultures in solutions of NaOH (or $NaHCO_3$) and of KOH (or $KHCO_3$) after plant absorption (cf. Table 2, l, n), there was residual titrable alkalinity and the alkalinity absorbed was still much in evidence in the respective samples of the ground plant materials. These experimental results are in complete agreement with theoretical expectations. It is of interest to bear in mind that OH ions (or CO_3 ions or HCO_3 ions) must have been absorbed in amounts equivalent to the NH_4, Na, and K ions absorbed from the respective solutions (cf. Table 2, i, l, n). Ammonium nitrate is but the product of the neutralization of HNO_3 with NH_4OH. The close agreement of the titrable acidities of the residual solutions and of the pH values of the aqueous suspensions of the ground plant materials among HNO_3, H_2O, NH_4NO_3, and NH_4HCO_3 is entirely in accordance with the theoretical expectations presented here and elsewhere (3).

The situation is made somewhat more complicated when $NaNO_3$ or KNO_3 are used as the sources of nitrogen. It is evident from the theory developed that 1 equivalent of H ions is as indispensable as 1 equivalent of NO_3 ions in the transformation of 1 gram-atom of N as NO_3 to the same amount of N in a pure protein. The dissociation of water gives a small concentration of H ions. As these are withdrawn with the NO_3 ions for protein formation further dissociation of water furnishes more H ions leaving the OH ions behind which, with the

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[5] Because of the CO_2 given off by the plant roots and the CO_2 capable of being absorbed by the culture solution from the atmosphere, we recognize for the conditions of the experiment very little difference between NH_4OH and NH_4HCO_3.

CO_2 present in the system, are changed to HCO_3 ions. This alkalinity must be divided between the plant and the residual culture solution unless other reactions have tended to neutralize it.

It has been suggested (13) that the basic and acidic parts of the dissolved salts are absorbed more or less independently of one another. If the absorption were absolutely independent, it would be expected in our experiments that the alkalinity remaining in the $NaNO_3$ culture solution would be greater, at least to some extent, than that from the $NaHCO_3$ because the "physiologically" formed $NaHCO_3$ would have an average concentration during absorption less than in the solutions where $NaHCO_3$ was chemically supplied. But the residual $NaHCO_3$ "physiologically" formed (cf. Table 2, m) is less than that where it was supplied chemically (cf. Table 2, n). From a point of view of independent absorption of the various compounds, it would seem as if in addition to the absorption of HNO_3 and $NaHCO_3$ there was an absorption of $NaNO_3$. Another way of stating the process, to get essentially the same results, would be to postulate the absorption of the $NaNO_3$ by the plant with the subsequent secretion of $NaHCO_3$ as the HNO_3 was transformed toward protein formation. More evidence seems desirable before accepting this point, however.

In considering the utilization of nitrogen from ammonium compounds, as shown above, it is in the form of NH_4OH that this is utilized to form proteins. In this case again the OH ions were secured by the dissociation of H_2O into OH ions and H ions. As the OH ions were removed with the NH_4 ions, more water dissociated and the H ions accumulated in the culture solution. But the mineral acid so formed with the anions of the ammonium salt is capable of being absorbed. This is shown by the absorption of these acids when they are used as the sole compounds respectively in the culture solutions. In the comparisons, the acids originally added have been absorbed to a greater extent than those "physiologically" formed. These results would more nearly coincide with a theory of the independent absorption of NH_4OH and of H_2SO_4 or HCl. Still more evidence would be desirable on this point, although work already reported points somewhat to independent absorption of NH_4OH (4, 7, 9, 11).

In the case of the absorption and utilization of nitrogen from the $NaNH_4HPO_4$, the results would indicate that the absorption consisted largely in the splitting off of NH_3 (i. e. NH_4OH) and the leaving of NaH_2PO_4.

ENERGY RELATIONS

The writer has not taken up the energy relations involved in these different transformations experimentally. However, the theories developed elsewhere (3) with which the experiments herein reported agree, have an interesting bearing on the work which others have done investigating the factors which encourage relative NO_3 and NH_4 ion absorption.

If proteins are oxidized to yield the N in the form of NH_3 or (if dissolved in water) NH_4OH, energy is liberated. Most of this energy is due to the oxidation of the C part of the proteins, but undoubtedly part of it results from the N transformation to NH_4OH. Again let the NH_4OH be oxidized to HNO_3. Here energy is likewise liberated. But very rarely are plants offered NH_4OH or HNO_3 as such in culture solution. It is usually offered in the forms of $(NH_4)_2SO_4$ and $NaNO_3$. In order to get $(NH_4)_2SO_4$ from NH_4OH it is necessary to add H_2SO_4. As is well known, this process of neutralization liberates energy by the union of the OH ions of the NH_4OH and the H ions of H_2SO_4. Again, if NaOH (or even $NaHCO_3$) is added to the HNO_3 secured from the protein oxidation, the energy of neutralization is liberated also.

The plant in the formation of these proteins with nitrogen supplied as $(NH_4)_2SO_4$ must dissociate H_2O into its constituent ions taking the OH ions to go with NH_4 ions and leaving the H ions behind. In the subsequent transformation of NH_4OH to protein N, undoubtedly the plant must spend additional energy.

In the formation of proteins from N furnished as $NaNO_3$ the plant must expend energy in each of the following steps: (a) In dissociating H_2O to secure H ions to go with the NO_3 ions, (b) in reducing HNO_3 to NH_4OH, and (c) in transforming NH_4OH to protein nitrogen.

If energy considerations involved in these processes affect the rates of absorption it would naturally follow that, (a) plants would absorb NO_3 ions more rapidly from a more acid medium because it would there be easier for them to secure the requisite H ions to go with the NO_3 ions for protein formation. (b) Plants would absorb NH_4 ions more rapidly from a more alkaline medium because it would be easier for them to secure the OH ions necessary to go with the NH_4 ions for the formation of proteins. (c) Plants would absorb NH_4 ions more rapidly than NO_3 ions where both are present in approximately equal concentrations in culture solutions nearly neutral in reaction because less energy would be required to transform NH_4 nitrogen to protein nitrogen than NO_3 nitrogen.

The observations of many experimenters (2, 8, 10, 11, 12, 14, 15, 16) are in more or less qualitative agreement with these predictions. This is apparently more so with young plants than with older ones. Many factors undoubtedly influence the applicability of energy considerations to absorption processes. Further work is undoubtedly necessary to establish what these various factors are and to find out the influence of each.

SUMMARY

1. The experimental procedure included complete utilization of the nitrogen in the single salt solutions by the sorghum and maize seedlings used. Simultaneous comparisons were made between parallel solution cultures. Typical comparisons included NH_4Cl *vs.* HCl, $NaNO_3$ *vs.* $NaHCO_3$, etc. Titrable acidity of the solutions before and after absorption and the pH values of the dried and ground plants after absorption were determined.

2. Parallel cultures of $(NH_4)_2SO_4$ *vs.* H_2SO_4 and of NH_4Cl *vs.* HCl gave residual titrable acidity in each case after the disappearance of the NH_4 ions from the cultural solutions. The residual liquids

from the ammonium salts showed a greater amount of acidity than did those where the acid was supplied chemically. The pH determinations of the ground material showed that the acids absorbed or physiologically formed within the plants were still in evidence.

3. Parallel cultures of $NaNO_3$ *vs.* $NaHCO_3$ and KNO_3 *vs.* $KHCO_3$ gave residual titrable alkalinity in each case after the disappearance of NO_3 ions from the cultural solutions. The residual liquids from the nitrate salts gave smaller amounts of alkalinity in each comparison. The alkalinity absorbed or physiologically formed in each case was clearly shown as still present by the pH determinations of the ground plants.

4. Parallel cultures in solutions of HNO_3, NH_4NO_3, NH_4HCO_3, and H_2O after absorption of all NH_4 and NO_3 ions gave small amounts of titrable alkalinity in each case. These titration values were practically equal to each other, although the orignal solutions of HNO_3 had had marked titrable acidity and those of NH_4HCO_3 marked titrable alkalinity. The pH values determined on the plants from the nitrogen compounds furnished in this group were practically equal to those on the plants grown in water. This showed that the acidity and alkalinity absorbed by plants in this group had largely disappeared in the transformations following absorption. These findings are in accord with theories previously proposed.

5. The plants must use energy in forming proteins from NH_4 and NO_3 compounds. The amounts of energy required to secure OH ions to go with the NH_4 ions and of H ions to go with NO_3 ions seem to bear a qualitative relationship to the rates of NH_4 and NO_3 ion absorption from solutions of different pH values.

LITERATURE CITED

1. Allison, F. E. The comparative effects of concentrated nitrogenous fertilizers on permanent soil acidity. Jour. Amer. Soc. Agron., 23 : 878–908. 1931.
2. Breazeale, J. F., and McGeorge, W. T. Nutritional disorders in alkaline soils as caused by deficiency of carbon dioxide. Ariz. Agr. Exp. Sta. Tech. Bul. 41 : 113–153. 1932.
3. Conrad, John P. Acidity and alkalinity produced by changes in the nitrogen, sulfur, and carbon cycles. Plant Phys., 8 : 509–524. 1933.
4. Cooper, W. C., Jr., and Osterhout, W. J. V. The accumulation of electrolytes. I. Entrance of ammonia into *Valonia macrophysa.* Jour. Gen. Phys., 14 : 117–125. 1930.
5. Engel, H. Bietrage zur Kenntnis des Stickstoffumsatzes grüner Pflanzen. Planta, 7 : 133–164. 1929.
6. Hoagland, D. R. The effect of the plant on the reaction of the culture solution. Calif. Agr. Exp. Sta. Tech. Paper 12 : 1–16. 1923.
7. ———— and Davis, A. R. The composition of the cell sap of the plant in relation to the absorption of ions. Jour. Gen. Phys., 5 : 629–646. 1923.
8. ————, ————. Suggestions concerning the absorption of ions by plants. New Phyt., 24 : 99–111. 1925.
9. Jaques, A. G., and Osterhout, W. J. V. The accumulation of electrolytes III. Behavior of sodium, potassium, and ammonium in *Valonia.* Jour. Gen. Phys., 14 : 301–314. 1930.
10. Loo, T. L. Studies on the absorption of ammonia and nitrates by the roots of *Zea mays* seedlings in relation to the concentration and actual acidity of culture solution. Jour. Fac. Agr. Hokkaido Imp. Univ. (Japan), 30 : 1–118. 1931.

11. Mevius, W., and Engel H. Die Wirkung der Ammoniumsalze in ihrer Abhängigkeit von der Wasserstoffionkonzentration. Planta, 9 : 1–83. 1929.
12. Naftel, J. A. The absorption of ammonium and nitrate nitrogen by various plants at different stages of growth. Jour. Amer. Soc. Agron., 23 : 142–158. 1931.
13. Pantanelli, E. Über Ionenaufnahme. Jahrb. f. wis. Botanik, 56 : 689–730. 1915.
14. Sessions, A. C., and Shive, J. W. The effect of culture solutions on growth and nitrogen fractions of oat plants at different stages of their development. Soil Science, 35 : 355–374. 1933.
15. Stahl, A. L., and Shive, J. W. Studies on nitrogen absorption from culture solutions. I. Oats. Soil Science, 35 : 375–399. 1933.
16. Tiedjens, V. A., and Robbins, W. R. The use of ammonia and nitrate nitrogen by certain crop plants. N. J. Agr. Exp. Sta. Bul. 526 : 1–46. 1931.

A COMPARISON OF LEGUME INTERCYCLE CROPS FOR PINEAPPLES[1]

O. C. Magistad, N. King, and O. N. Allen[2]

In spite of the fact that 80 to 120 tons per acre of green and partially dried pineapple plants are shredded and after some decomposition incorporated with the soil, it has been the custom in the pineapple industry to grow a grass or leguminous crop prior to replanting the field with pineapples a year or two later. This intercycle crop adds additional organic matter, prevents loss of nutrients by erosion and leaching, and, if a legume, adds some fixed nitrogen.

This paper presents information on the relative advantages of six leguminous plants when compared with each other, their yields, nitrogen contents, and agricultural operations.

PLAN OF EXPERIMENT

The experiment was installed at the Wahiawa sub-station of this Experiment Station under conditions of low summer rainfall. The six leguminous plants selected for this study were as follows: *Cassia tora*, *Crotalaria anagyroides*, *C. juncea*, *C. spectabilis*, *Stizolobium utile*, and *Cajanus cajan*.

For 3 years prior to the planting of these plants this area had been growing pineapple hybrids. The pineapple plants were shredded early in November, 1931, shortly after harvest, and subsequently incorporated with the soil. In this manner approximately 100 tons of green matter per acre were turned under. The field was plowed and harrowed on three occasions. By March 1932 all of the plant material had practically decomposed, leaving the soil in good condition for subsequent planting.

The experiment was installed as a Latin square experiment with 36 plats, 6 on a side. A diagram of the plat distribution together with

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[2] Chemist, Agriculturalist, and Cooperating Soil Bacteriologist, respectively.

the legume grown on each is given in Fig. 2. Each plat was 53.33 x 45.75 feet or 0.0560 acre. Planting was done on March 11 and 12 with a seeder to a depth of 2 inches. The lines were spaced 20 inches apart.

The rates of planting in pounds per acre were as follows: *Cassia tora*, 20; *Crotalaria anagyroides*, 25; *C. juncea*, 30; *C. spectabilis*, 15; *Stizolobium utile*, 50; and *Cajanus cajan*, 100.

The soil at the time of planting was moist, the rainfall during 1932 and up to March 12 having been 25.54 inches distributed as follows: January, 4.17 inches; February, 19.77 inches; and March 1 to 12, 1.60 inches.

Three days before planting the plats received 1.06 inches of rainfall. Prior to field planting all of the seed received an ample inoculum of nodule-forming bacteria with the exception of *Cassia tora*, as recent results by Allen and Allen (1)[3] have shown that this leguminous plant does not bear nodules nor does it bear symbiotic micro-organisms within its tissues.

Germination of the seeds was rapid and regular in the case of *Crotalaria anagyroides* and *C. juncea*, while the seed germinations of *C. spectabilis*, *Cajanus cajan*, and *Cassia tora* were more or less irregular. *Stizolobium utile* required about 10 days for maximum germination. However, the subsequent stand was good. A small amount of replanting in certain pigeon pea lines 3 weeks after the initial planting was deemed expedient in order to cover vacancies produced by lack of germination.

The test as a whole progressed favorably with the aid of frequent light showers. Flowering began on *Crotalaria juncea* the first week in May and reached a peak 2 weeks later. Weed growth occurred in all plats but was most pronounced in the areas containing *Cassia tora* and *Crotalaria spectabilis*. Two months after planting *Stizolobium utile* had produced a dense mat of growth over the ground. Weed growth was considerably less in these areas. The growth of the plants 170 days after planting is shown in Fig. 1.

The status of the different varieties at various periods during the test is indicated in Table 1.

TABLE 1.—*Plant growth and soil conditions during the test.*

Legume	Three months weeds	Five months stand	Flowering	Seed production	Soil condition one month after plowing
C. anagyroides	Light	±60 inches	4th month start	Low, protracted	Hard and lumpy
C. cajan......	Light	±50 to 54 in.	4th month	Medium	Lumpy
C. spectabilis..	Heavy	±50 inches	4th month	Very heavy	Lumpy
C. tora.......	Very heavy	24 to 30 in.	None	None	Large clods
S. utile.......	Very light	Vine tangle, ±36 in. deep	5th month heavy, protracted	Fairly heavy, protracted	Loamy
C. juncea.....	Medium	±50 inches	3rd month	Very heavy	Slightly lumpy

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[3] Figures in parenthesis refer to "Literature Cited," p. 380.

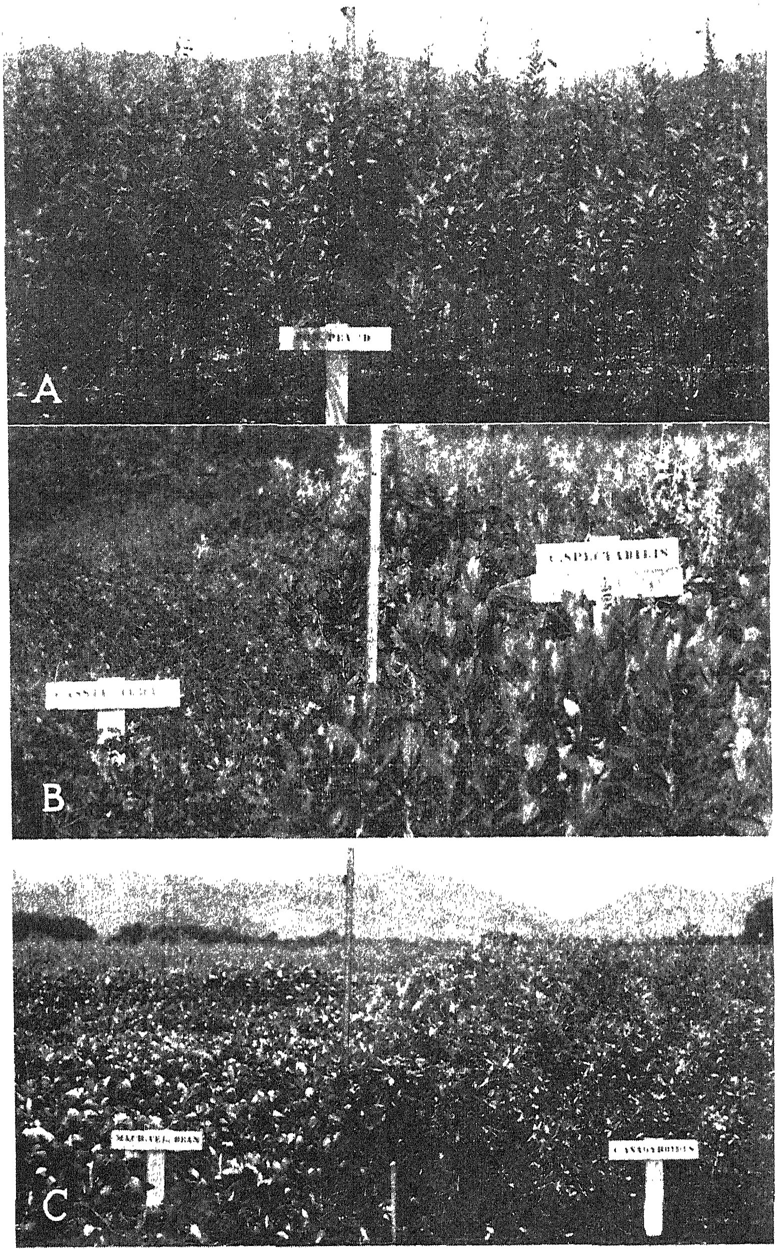

FIG. 1.—Growth of test plants 170 days after planting. A, *Cajanus cajan* (pigeon pea); B, *Cassia tora* and *Crotalaria spectabilis*; C, *Stizolobium utile* and *Crotalaria anagyroides*.

The plants were plowed under on November 15, 1932, with a McCormick Deering gang plow of recent design having 28-inch discs. The tall plants, *Crotalaria anagyroides*, *Cajanus cajan*, and *Crotalaria spectabilis*, were handled with ease as they were completely buried under the plow slice. The dense mat of velvet bean vines gave the most trouble since it resisted cutting by the discs, bunched up, and thus skidded over the ground surface, leaving the plant material in spots. A heavier plow might have been able to cut through the mass of vines with less trouble.

Rainfall during the growth period was as follows: March 12 to 31, 2.10 inches; April, 3.32 inches; May, 1.69 inches; June, 2.86 inches; July, 2.07 inches; and August, 1.61 inches, with a total of 13.65 inches. The rainfall during this period can be considered good since the average rainfall for the years 1928 to 1932, inclusive, for this growing period was only 11.68 inches.

YIELD AND NITROGEN CONTENT

On June 10, 91 days after planting, two separate areas of 1/3,000 acre each were harvested in each plat. Wet weights, moisture, and nitrogen analyses were made.

C. anagyroides 2,196.00 75.00 3.02	*C. cajan* 982.00 73.50 2.41	*C. spectabilis* 1,489.00 80.50 3.26	*C. tora* 922.00 75.50 1.44	*S. utile* 2,815.00 78.50 1.87	*C. juncea* 1,689.00 73.50 2.41
C. tora 744.00 75.50 1.31	*S. utile* 2,379.00 77.50 2.15	*C. anagyroides* 1,580.00 76.00 2.71	*C. juncea* 2,283.00 71.00 2.25	*C. cajan* 480.00 71.00 2.02	*C. spectabilis* 1,880.00 80.00 2.97
C. spectabilis 1,176.00 80.00 3.41	*C. juncea* 2,792.00 67.00 2.34	*C. cajan* 1,176.00 70.00 2.11	*S. utile* 2,776.00 78.00 1.67	*C. anagyroides* 1,760.00 75.00 3.07	*C. tora* 652.00 75.00 1.45
S. utile 2,950.00 77.50 2.33	*C. anagyroides* 2,217.00 73.50 2.51	*C. tora* 538.00 72.50 1.46	*C. spectabilis* 1,044.00 80.00 3.04	*C. juncea* 2,127.00 69.50 2.43	*C. cajan* 1,632.00 70.50 2.27
C. juncea 1,872.00 65.50 2.13	*C. spectabilis* 902.00 79.00 3.33	*S. utile* 2,415.00 77.00 3.16	*C. cajan* 955.00 68.50 2.72	*C. tora* 663.00 70.00 1.92	*C. anagyroides* 1,224.00 72.50 2.88
C. cajan 895.00 66.00 2.51	*C. tora* 1,239.00 67.50 2.21	*C. juncea* 1,947.00 66.50 2.46	*C. anagyroides* 1,091.00 73.50 2.57	*C. spectabilis* 786.00 78.50 3.41	*S. utile* 2,108.00 77.00 2.08

FIG. 2.—Diagram of plat distribution and yield data for the various leguminous plants at the end of 91 days.

Again on August 15, 157 days after planting, harvesting was repeated in the same manner. Figs. 2 and 3 show the data obtained in each plat of 2/3,000 acre. The *first* figure in each cell gives the wet weight in grams, the *second* figure the moisture content on the wet basis, and the *third* figure the nitrogen percentage on the dry basis.

C. anagyroides 5,352.00 735.00 2.06	*C. cajan* 2,449.00 66.00 2.00	*C. spectabilis* 5,988.00 76.50 2.24	*C. tora* 2,041.00 74.00 1.24	*S. utile* 7,439.00 80.00 2.40	*C juncea* 1,588.00 50.50 2.18
C. tora 1,089.00 70.00 1.45	*S. utile* 4,672.00 82.50 2.67	*C. anagyroides* 4,128.00 74.00 1.79	*C. juncea* 1,633.00 56.50 1.31	*C. cajan* 1,905.00 65.00 1.73	*C. spectabilis* 5,761.00 74.50 2.20
C. spectabliis 5,171.00 76.50 2.58	*C. juncea* 2,404.00 57.50 1.49	*C. cajan* 4,717.00 66.50 1.54	*S. utile* 7,484.00 80.00 2.44	*C. anagyroides* 4,082.00 75.00 2.26	*C. tora* 1,225.00 70.50 1.32
S. utile 7,167.00 80.00 1.88	*C. anagyroides* 5,080.00 73.00 2.22	*C. tora* 1,089.00 74.00 1.18	*C. spectabilis* 4,309.00 77.50 2.24	*C. juncea* 2,495.00 59.00 2.05	*C. cajan* 3,946.00 65.00 1.68
C. juncea 1,724.00 61.00 1.98	*C. spectabilis* 4,309.00 79.00 2.62	*S. utile* 8,981.00 80.00 3.46	*C. cajan* 3,130.00 67.00 1.80	*C. tora* 2,495.00 67.50 1.37	*C. anagyroides* 5,534.00 75.00 2.00
C. cajan 3,856.00 69.00 2.03	*C. tora* 3,357.00 65.00 1.76	*C. juncea* 1,950.00 60.00 1.83	*C. anagyroides* 3,992.00 70.00 1.75	*C. spectabilis* 3,538.00 81.00 2.72	*S. utile* 6,033.00 80.50 2.18

FIG. 3.—Diagram of plat distribution and yield data for the various leguminous plants at the end of 157 days.

A summary of the moisture content and nitrogen percentages of each legume is given in Table 2.

TABLE 2.—*A summary of moisture contents and percentages of nitrogen for each legume at the end of 91 and 157 days.*

Legume	Moisture on wet basis, %		Nitrogen on dry basis, %	
	91 days	157 days	91 days	157 days
C. cajan.	69.92±0.76	66.42±0.43	2.34±0.080	1.80±0.052
C. juncea.	68.83±0.96	57.42±1.15	2.34±0.025	1.81±0.101
C. spectabilis.	79.67±0.16	77.33±0.69	3.23±0.081	2.43±0.077
C. anagyroides.	74.25±0.40	73.42±0.54	2.78±0.097	2.01±0.071
S. utile.	77.58±0.25	80.50±0.31	2.21±0.156	2.51±0.165
C. tora.	72.67±0.78	70.17±0.97	1.63±0.399	1.37±0.073

The yield data obtained were treated as advocated by Fisher and Wishart (3) for Latin square experiments. A table for the analysis of variance was prepared to evaluate the error in the experiment. This is given in Table 3 for wet weights at 91 days.

TABLE 3.—*Analysis of variance, wet weights, 91 days old.*

Due to	Degrees of freedom	Sum of squares	Mean square	Standard deviation	½ log e mean square	Observed Z
Rows......	5	347,920	79,545	282.03	5.6420	
Column....	5	1,041,115	208,223	456.31	6.1243	
Treatments	5	14,130,250	2,826,050	1,681.08	7.4285	
Errors.....	20	2,870,675	143,534	378.80	5.9381	1.4904
Total....	35	18,389,960				

The Z value given in the last column of Table 3 is the difference between ½ log e of the mean square of treatment minus that of error. This value is 1.4904. Reference to Table 6 of Fisher's "Statistical Methods for Research Workers" gives 0.5100 as the Z value for an experiment such as ours with a probability of 0.05. Our Z value exceeds this greatly, indicating that the experiment as a whole was highly significant and that differences between treatments are far greater than the error involved.

The results of the experiment have been condensed and are given in final form in Table 4.

TABLE 4.—*A comparison of wet weights, dry weights, and nitrogen content of six legumes, all values in pounds per acre.*

	C. cajan	*C. juncea*	*C. spectabilis*	*C. anagyroides*	*S. utile*	*C. tora*	Standard deviation of variety	Difference for significance
Wet wt., 91 days.....	3,373	7,006	4,010	5,548	8,511	2,620	208.7	616.8
Wet wt., 157 days....	11,025	6,500	16,025	15,525	23,000	6,225	483.0	1,427.0
Dry wt., 91 days.....	1,013	2,192	809	1,423	1,904	728	19.12	56.5
Dry wt., 157 days....	3,690	2,752	3,659	4,115	4,522	1,922	175.70	519.2
Nitrogen, 91 days....	23.84	51.15	25.95	39.81	41.95	12.60	1.74	5.14
Nitrogen, 157 days...	65.43	49.72	87.60	83.00	115.03	28.18	4.47	13.2

DISCUSSION

In Table 4 we note that at 91 days velvet beans had produced the greatest yield, namely, 8,511 pounds per acre on the wet basis. The next highest yield is 7,006 pounds per acre by *Crotalaria juncea.* Each of these yields has a standard deviation of 208.7. Therefore, the difference is 1,505 pounds with a standard deviation of $\sqrt{2}$ x 208.7, or 295.1 pounds. Let us accept odds of 20:1 as significant.

Such odds occur in the case of 20 degrees of freedom when the difference divided by the standard deviation of the difference is equal to 2.09. In other words, whenever the difference exceeds $2.09\sqrt{2}$ standard deviation of a treatment it is significant. In the case above the difference must exceed $2.09\sqrt{2}$ (208.7), or 616.8 pounds. Since the actual difference was 1,505 pounds, the above results become highly significant and thus show that *Stizolobium utile* produced a greater yield than *Crotalaria juncea* and all the other leguminous plants in 91 days on the basis of wet weights. On the basis of wet weights at 157 days, the yield of *S. utile* also significantly exceeded that of the other plants.

When dry weights at 91 days are considered *Crotalaria juncea* significantly outyielded the other legumes. This species matures very early and in our test was in full bloom at an age of about 10 weeks. Consequently, at the age of 91 days it had already begun to harden and its moisture content was less than any of the other plants used in this test.

At 157 days *Stizolobium utile* contained considerably more dry matter than at 91 days and at this time on the dry matter basis its yield was significantly greater than the other plants with the exception of *Crotalaria anagyroides*.

During the entire growth period of *Cassia tora* with the exception of the first few weeks the plants were yellowish green in color indicating that the plants were not obtaining an ample supply of nitrogen from the soil. The inability of these plants to fix nitrogen is reflected in the low percentages of nitrogen at both 91 days and 157 days as shown in Table 4. The values here are 1.63 ± 0.399 and 1.37 ± 0.073, respectively, compared with 2.21 ± 0.156 and 2.51 ± 0.165 per cent for *Stizolobium utile*.

There seems to be little reason for not conceding that *Cassia tora* contained all the available nitrogen on the acre basis that the soil was able to furnish during the period of growth. It seems logical also to assume with little chance of error that the nitrogen contents of the other plants in excess of 28 pounds per acre was fixed nitrogen. If 13 pounds of nitrogen per acre are included as a possible error, *Stizolobium utile* has fixed 115 minus 41, or 74 pounds of nitrogen per acre during the period of 157 days. On this same basis all the other leguminous plants, with the exception of *Cassia tora*, have fixed some atmospheric nitrogen.

It is believed that a lack of available phosphorus and of rainfall were limiting factors of growth in the above experiment. The quantity of easily soluble P_2O_5 in this area as determined by the Truog method was 6.6 p.p.m. on the dry soil basis. For best growth as indicated by various grass crops in pot studies, the available P_2O_5 level should have been 50 p. p. m. or more. That this also holds for these plants is indicated by the very great responses to phosphorus obtained by *Cajanus cajan* in a number of former field experiments.

The literature is replete with references indicating that leguminous plants grow best and fix more nitrogen on soils near neutrality as opposed to acid conditions. This has been very clearly demonstrated by Magistad and Allen (7) in the case of pigeon peas in another field where liming a soil of pH 4.0 raised the pH value to about pH 5.0 and increased the yield from 4.98 to 12.24 tons per acre.

The experimental area in the present experiment had a pH value of 4.88 based on an average of five samples. It is very probable that this soil was too acid for best results with these legumes.

Pigeon pea has long been grown in the territory (5). Yields in general have been considerably better than obtained in this particular test. Krauss (5) reports that Whitmore obtained an estimated yield of 20 tons green forage at 6 months. The senior author has obtained yields of 15 tons green weight per acre containing 252 pounds nitrogen at the age of 10 months. In another experiment with phosphate fertilization a yield of 35 tons green weight per acre containing 500 pounds of nitrogen was obtained. Arsenaux, *et al.* (2) have reported a yield of 22 tons green weight in 119 days in Louisiana.

Crotalaria juncea was grown in the territory as early as 1917 (5). Johnson, Thompson, and Sahr (4) on the basis of pot yields reported an estimated green weight per acre of 10 to 26 tons. In a later publication, Thompson (8) gives the percentage of nitrogen on the dry basis, ranging from 1.91 to 3.73. Arsenaux, *et al.* (2) report the greatest dry matter content of *Crotalaria juncea* at full bloom, age 110 days. The green matter yield was 33.8 tons per acre, moisture 71.89 and nitrogen 226 pounds per acre, or 1.18% on the dry basis.

Crotalaria anagyroides was also included in the list of plants tried by Arsenaux, *et al.* (2). They emphasized the use of this leguminous plant chiefly because of its high yield, namely, 21.37 tons green weight in 119 days after planting.

Leonard and Reed (6) reported good results with *Crotalaria spectabilis.* They obtained a yield of 4,296 pounds dry hay per acre with a nitrogen content of 1.65%, 120 days after planting. It is to be noted that this is a better yield than obtained by us.

SUMMARY

These experiments were conducted at the Wahiawa Sub-station, Island of Oahu, T. H., with the purpose of testing the value of six leguminous plants, namely, *Cajanus cajan*, *Crotalaria juncea*, *C. spectabilis*, *C. anagyroides*, *Stizolobium utile*, and *Cassia tora* under ordinary growth conditions.

1. The Latin square method of plat arrangement was followed. The soil of the plats was acid, pH value 4.9, and very low in available phosphorus. Both of these conditions were unfavorable to the good growth of the tested crops.

2. Relative germination of the respective lots of seed, tonnage of the crops on a wet and dry basis, and amount of nitrogen fixed were considered as indices of the suitability of the crops. The data were mathematically interpreted.

3. *Cassia tora* did not prove acceptable as a cover crop under any conditions provided in this test.

4. The plants tested may be divided into two general groups with respect to growth period. *Crotalaria juncea* and *Stizolobium utile* excelled in wet weight and nitrogen content at the end of the 91-day period. *Crotalaria juncea* had produced at this period 7,006 pounds

of wet material of which 68.83 ± 0.96% was moisture and 2.34 ± 0.025% nitrogen, while *Stizolobium utile* produced 8,511 pounds of wet material containing 77.58 ± 0.25% moisture and 2.21 ± 0.156% nitrogen. The remaining plants, together with *S. utile*, proved most acceptable after 157 days of growth.

5. In brief, the legumes may be arranged in descending order with respect to the following:

A. Wet weight at the end of the 91-day period: *Stizolobium utile, Crotalaria juncea, C. anagyroides, C. spectabilis, Cajanus cajan, Cassia tora.*

B. Wet weight at the end of 157 days: *Stizolobium utile, Crotalaria spectabilis, C. anagyroides, Cajanus cajan, Crotalaria juncea, Cassia tora.*

C. Dry weights at the end of 91 days: *Crotalaria juncea, Stizolobium utile, Crotalaria anagyroides, Cajanus cajan, Crotalaria spectabilis, Cassia tora.*

D. Dry weights at the end of 157 days: *Stizolobium utile, Crotalaria anagyroides, Cajanus cajan, Crotalaria spectabilis, C. juncea, Cassia tora.*

E. Nitrogen content at the end of 91 days: *Crotalaria juncea, Stizolobium utile, Crotalaria anagyroides, C. spectabilis, Cajanus cajan, Cassia tora.*

F. Nitrogen content at the end of 157 days: *Stizolobium utile, Crotalaria spectabilis, C. anagyroides, Cajanus cajan, Crotalaria juncea, Cassia tora.*

LITERATURE CITED

1. ALLEN, ETHEL K., and ALLEN, O. N. Attempts to demonstrate symbiotic nitrogen-fixing bacteria within the tissues of *Cassia tora*. Amer. Jour. Bot., 20 : 79–84. 1933.
2. ARCENEAUX, G., MCKAIG, N. Jr., and STOKES. T. E. Studies of soybeans and other green manure crops for sugar cane plantations. Jour. Amer. Soc. Agron., 24 : 354–363. 1932.
3. FISHER, R. A., and WISHART, J. The arrangement of field experiments and the statistical reduction of results. Imp. Bur. Soil Sci., Tech. Comm. 10, 1930.
4. JOHNSON, M. O., THOMPSON, A. R. and SAHR, C. A. Comparative value of legumes as green manures. Hawaii Agr. Exp. Sta. Press Bul. 52. 1917.
5. KRAUSS, F. G. The pigeon pea (*Cajanus indicus*), its improvement, culture, and utilization in Hawaii. Hawaii Agr. Exp. Sta. Bul. 64. 1932.
6. LEONARD, L. T., and REED, H. R. A comparison of some nodule forming and non-nodule forming legumes for green manuring. Soil Science, 30 : 231–236. 1930
7. MAGISTAD, O. C., and ALLEN, O. N., Effect of liming on the growth of pigeon peas in Hawaiian soils. Philippine Agr., 21 : 659–664. 1933.
8. THOMPSON, A. R. Chemical studies of the efficiency of legumes as green manures in Hawaii. Hawaii Agr. Exp. Sta. Bul. 43. 1917.

SOME INDICATIONS OF A RELATION OF SOIL FERTILITY AND PLANT NUTRITION TO CANE DISEASES IN HAWAII[1]

A. FLOYD HECK

The history of the sugar industry in Hawaii shows an increasing tendency toward susceptibility of cane to disease. The three diseases causing the greatest losses are probably growth failure or Lahaina disease, eye spot, and brown stripe. There are other diseases, but these have received the greatest attention, not only from the pathologists, but from the chemists and agriculturists as well. There has been not only an increasing susceptibility to these diseases, but also an increasing severity of them.

In the early years of the sugar industry in Hawaii, Lahaina was the cane variety grown almost exclusively. At that time, little fertilizer was used, and this, as a rule, was low in nitrogen. Areas of poor cane developed, and in time much of the Lahaina was making poor growth. In a short time the Lahaina failed almost entirely and was displaced by Yellow Caledonia and H 109. But with the changes in variety, growth failure did not entirely disappear, and at the present time appears to be increasing in severity.

Recent investigations (3)[2] show this disease to be associated with a root-rot and the organism *Pythium aphanidermatum*. It has been called *Pythium* root-rot of cane, but in this paper the term growth failure will be used. Whether the *Pythium* is the direct cause of the disease or whether it is secondary as the result of a weakened physiological condition, due to a plant nutrient deficiency or an unbalanced nutrition, is an open question. Some doubt that the severity of growth failure is on the increase, but many who are in daily contact with field conditions believe that it is not only becoming more severe, but that it is spreading and beginning to affect varieties which have hitherto been considered resistant to this disease.

Eye spot and brown stripe are both *Helminthosporium* diseases. The former is caused by *H. sacchari* (5), and the latter by *H. stenospilum* (2, 5). Both are disseminated by spores and are characterized by small lesions on the leaves. The injury caused by these two diseases appears to result largely from a reduction of the active leaf surfaces. This may be due to the death of the tissue within the lesion itself or to a secondary effect of the organisms on the tissue outside of the lesion, and the extent of the injury seems to be in almost direct proportion to the extent of leaf surface affected.

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[1] The samples for this work were collected while the writer was with the Experiment Station of the Hawaiian Sugar Planters Association, and the work completed in the Department of Soils, University of Wisconsin, Madison, Wis. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication July 31, 1933.

[2] Numbers in parenthesis refer to "Literature Cited", p. 389.

NATURE OF THE SOILS OF HAWAII

Up to the present time these diseases have been studied mainly from the standpoint of the organisms with which they are associated, rather than from the standpoint of the relation of the environmental conditions to the disease. Recently, evidence has begun to accumulate to substantiate the idea that nutritional conditions may have a great deal of influence upon the severity of these diseases. In general, the soils of Hawaii are ill adapted to furnish a balanced nutrition. Most of the soils of Hawaii are of a lateritic character. Although they may not be classed as true laterites, they are generally high in iron and aluminum and relatively low in silicon. Most of the upper lands are red or reddish yellow, with the few dark-colored soils usually of low altitude and near the sea. Most of the soils, even those of higher altitudes, contain a fair amount of nitrogen and organic matter. However, this organic matter is very inactive, and nitrification and biological activities go on very slowly. Few of these soils have any marked tendency to produce a favorable biological balance (4) of plant nutrients, and consequently there is little control of nitrogen from this standpoint.

Most Hawaiian soils are fairly high in total phosphorus, but in the majority of cases the readily available form tends to be low, and, in many instances, is not more than a trace or a few parts per million. This is perhaps due to the presence in these soils of certain iron compounds which fix phosphorus in difficultly available form. From the low-lying, darker lands near the sea to the lands of higher altitudes where the soils are distinctly red, there is a marked decrease in the readily available phosphorus, and also a greater tendency for the higher lands to fix phosphorus in difficultly available form. This combination makes the phosphorus deficiency in the higher lands more marked and more difficult to correct.

Most of these soils are fairly well supplied with replaceable potassium, with a tendency for it to be lower in the lower lying makai lands (near the sea), and higher in the red mauka lands (uplands). In general, this tends toward an unbalanced condition with respect to phosphorus and potassium, which, together with an inactive biological condition and the present method of fertilization, means that available nutrients are for the most part in an unbalanced condition. Even if a balanced fertilizer is used, the variation in the available soil phosphorus and potassium, the difference in the degrees of fixation of applied materials, and the unsatisfactory biological condition make it difficult to maintain a proper balance of available nutrients in the soil.

GROWTH FAILURE

The influence of this unbalanced condition in relation to disease was probably first noticed in connection with the growth failure of Lahaina and afterward to a lesser extent with H 109 and other varieties. Quite by accident it was found that where waste molasses from the sugar mill was spilled in a growth failure area there was a marked improvement in the cane. Later experiments with molasses, together with other materials, have shown that if the nutrition of the cane plant is properly balanced, the plant is less susceptible to the attack of the *Pythium* fungus. It has been found that an excess of mineral nitrogen in the form of either nitrate or ammonia (3) tends to render the plant more susceptible to attack, while organic nitrogen does not have this effect. One of the beneficial effects of the molasses seems to be due to its influence on the change of the mineral nitrogen to the organic form. This change is brought about by the yeasts and other micro-organisms (4) which grow on the sugars of the molasses. This greatly increased biological activity carries over for a number of years, giving the soil a better balance of available nutrients, especially nitrogen, and perhaps also phosphorus and potassium. The molasses may also carry as much as 80 to 90 pounds of potassium a ton, which may be of considerable importance in some soils.

The beneficial effect of phosphorus in this balancing action of the molasses is very significant. Where "press cake" or mud from the filters or clarifiers is added with the molasses, a greater benefit is obtained in the growth failure areas than where the molasses is used alone. Subsequent work with molasses has brought out the fact that phosphates applied with the molasses aid materially in effecting not only a better biological balance, but at the same time a better nutritional balance for the plant. At the Waipio Sub-station, the use of phosphorus, either in "press cake" or as rock phosphate, accelerated the biological activity and doubled the quantity of mineral nitrogen changed to the organic form. It seems that in the same way that phosphorus aids in biological activities to increase nitrification when the active organic content of the soil is low, so it also helps materially in the change of mineral nitrogen to the organic form when the soil is well supplied with carbonaceous energy material, such as that in the waste molasses.

The effect of phosphorus on the nitrogen and nutritional balance can be noticed in many ways. The immediate supply of nitrate nitrogen is much reduced, and, as a result of this reduction, the leaching and loss of nitrate is also reduced. If the energy in molasses, the mineral nitrogen, and the available phosphorus are properly balanced, the loss of nitrogen by leaching may be reduced to almost nothing. A further advantage in this change in the form of the nitrogen is that the nitrogen in the organic form is held in the surface soil and slowly becomes available as nitrate. In this way there is a tendency to form a natural biological balance of the plant nutrients and to maintain this balance over a longer period of time. Phosphorus not only aids in both of these nitrogen changes, but at the same time the level of available phosphorus is raised, and especially is this important in the higher lands which are usually low in readily available phosphorus. From practical observations it appears that there are certain factors in combination which are essential to bring about the proper balance of plant nutrients to correct growth failure conditions, and on some areas this balance seems to be almost impossible to obtain. This seems to account for the fact that the indiscriminate use of molasses to correct growth failure has not always been successful, and that its correction may depend upon factors other than those carried by the molasses.

Phosphorus and potassium, as well as nitrogen, seem to play a very important rôle in the varietal resistance to growth failure. The juices of the more resistant canes are usually higher in one or both of these mineral elements. When a more resistant variety replaces a more susceptible, the resistant variety, growing on the same soil, usually contains more phosphorus and potassium in the juice than the variety which failed. This is especially true of phosphorus on the red mauka lands, because of the low phosphorus availability and the very high fixing power of these soils for phosphorus. In general, it appears that the *Pythium* attack of the cane roots is greatly influenced by the nutritional balance of the plant, much the same as a lack of nitrogen in certain stages in the growth of the tobacco plant makes it susceptible to brown root-rot, a disease perhaps associated with a fungus not yet identified, but acting in many ways similar to the *Pythium* root-rot of cane. In relation to growth failure or Lahaina disease, it may be said that there is some question as to whether the disease is the direct result of the *Pythium* infection, or whether the *Pythium* infection is not a secondary condition resulting from a malnutrition of the plant due to an unbalanced soil condition.

EYE SPOT

Eye spot occurs, for the most part, during the winter months and in the lower lying lands. This disease does the greatest damage where there is an appreciable amount of nitrate nitrogen present in the soil at this time. Experience has shown that if nitrogen fertilization is withheld during the fall and winter months, the damage caused by eye spot is materially reduced. Infection is much worse during the winter months because of less sunshine, higher humidity, and lower temperatures. This combination of factors is more favorable for the germination of the spores. The damage, however, is not caused so much by the immediate presence of the organism in the tissue, but by the "runner"[3] which extends from the invaded area to the tip of the leaf, and which seems to be a secondary effect. This "runner" is always associated with a high nitrate content of the soil. It has been suggested that the "runner" is caused by the accumulation of nitrite nitrogen in that part of the leaf and the killing of the tissue. Just what part the organism plays in this, or the mechanism of its operation, is not known, but it has been definitely shown that low nitrates in the soil will prevent the formation of "runners." The withholding of nitrogen fertilization does not necessarily prevent infection, but, to a large extent, it does prevent the formation of "runners."

Field work done in Field Kawaihapai 1A at the Waialua Agricultural Company showed a high nitrate nitrogen content in lands where the cane was badly damaged by eye spot. Table 1 gives the amount and distribution of nitrate nitrogen in a badly damaged section of this field.

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[3] "Runner" is a term used to designate the dead or failing tissue which forms a narrow ribbon between the veins and extends from the eye spot invaded area to the tip of the leaf. A single runner is usually less than half an inch in width.

TABLE 1.—*Distribution of nitrate nitrogen in the soil of an eye spot infested area, Field Kawaihapai 1A, Waialua Agricultural Company, December 29, 1930.*

Sample No.	Nitrate nitrogen, p.p.m.		
	1st foot	2nd foot	3rd foot
Line (Row) Samples			
1	4.8	3.1	3.5
2	5.6	3.2	2.5
3	4.3	4.2	3.5
4	7.0	7.5	15.0
5	4.3	3.2	4.5
6	5.7	2.2	2.0
Kuakua (Ridge Between Rows) Samples			
1	35.0	62.0	19.0
2	33.0	20.5	8.0
3	31.0	15.0	5.7
4	62.0	52.0	19.0
5	60.0	20.5	10.6
6	42.0	12.6	7.5

With samples taken horizontally at intervals of 12 inches and vertically by feet to a depth of 3 feet, a further study of the vertical and horizontal distribution of nitrate nitrogen between lines of cane 6 feet apart was made. Table 2 shows this distribution of nitrates between the lines.

TABLE 2.—*Vertical and horizontal distribution of nitrate nitrogen between lines of cane in Field Kawaihapai 1A, Waialua Agricultural Company, January 9, 1931.*

Horizontal samples at 12-inch intervals	Nitrate nitrogen, p.p.m.		
	1st foot	2nd foot	3rd foot
A, Line (Row)	4.5	4.5	3.5
B	8.0	3.7	8.5
C	15.0	23.0	13.5
D, Kuakua (Ridge)	17.0	19.0	8.3
E	16.5	37.0	13.0
F	6.0	5.5	3.6
G, Line (Row)	6.0	3.7	7.5

These data show that there are large quantities of nitrate nitrogen in the soil of the eye spot infested areas. It is not only in the line (row) with the growing cane, but in the kuakua (ridge between the rows) to a very much greater extent and is continually being supplied to the weakened cane.

There is some question whether nitrogen is the only nutritional factor out of balance causing the severe loss from eye spot. Work done on the transition zone between eye spot and brown stripe seems to indicate that perhaps low potassium may also be a factor in that a lack of potassium may prevent the plant from assimilating the nitrogen as it should under normal growing conditions. Figures obtained on cane juice and the soil in Field Valley 2, Waialua Agricultural Company, indicate that perhaps potassium may be a factor in this regard. Table 3 gives these data.

TABLE 3.—*Analysis of cane juice (H 109) and soil from Field Valley 2, Waialua Agricultural Company, January 24, 1931.*

Sample	Disease condition	Cane juice, p.p.m.		Soil, p.p.m.			
		P	K	Readily available phosphorus		Nitrate nitrogen	
				1st ft.	2nd ft.	1st ft.	2nd ft.
A	Eye spot (makai)	42	880	30	25	7.2	21.0
B	Disease free (middle)	110	1,135	15	9	4.0	2.1
C	Brown stripe (mauka)	51	1,720	20	6	3.5	1.9

These samples were taken at a distance of 100 feet from each other across the transition zone between eye spot and brown stripe infestations. The cane infected with eye spot had a low potassium content of the juice as well as a high nitrate content of the soil when the juice samples were taken. This may be due, in part, to a lack of available potassium in the soil, and, in part, to an over-balance of available nitrogen which might cause an accentuation of the disturbance of the nutritional balance with potassium as well as with phosphorus. In either case the figures show an unbalanced condition with respect to nitrogen and the minerals, with susceptibility to eye spot as the result. In the disease-free area there seems to be a better balance between nitrogen, potassium, and phosphorus, and the result is greater resistance to disease. In the higher land, the potassium content of the cane juice is much greater and phosphorus appears to become the limiting factor, and in this area brown stripe begins to appear.

Pettinger (6) has used the juice of corn as an indicator of the plant's nutritional needs and thinks it reliable. The juice of cane should be even more reliable for cane is a longer growing plant of somewhat perennial nature, and does not possess the ripening habit of an annual like corn, and, as a result, the juice is much more constant in composition.

BROWN STRIPE

Brown stripe is a disease confined largely to the higher lands and usually does the greatest damage on the older cane or during the second year's growth. This disease is not confined to any one season, and usually is as bad during the summer as in the winter. For this reason it has been called "summer eye spot." Brown stripe is especially prevalent in areas low in readily available soil phosphorus. This can be seen on all of the islands, but especially is this true on

Kauai, where the availability of phosphorus is probably generally lower than on the other islands. However, the evidence is not conclusive that lack of phosphorus alone can be held as the cause of heavy brown stripe infection. On the other hand, there is almost as much evidence that potassium may be even as great a factor as phosphorus, either from a deficiency standpoint or in its balance relation with phosphorus.

First, considering phosphorus in its relation to brown stripe, it may be seen from the figures in Table 3 that the juice from sample C, infected with brown stripe, is low in phosphorus in proportion to the potassium it contains. This ratio, however, is not constant for all varieties, and another variety might show little susceptibility with this same ratio. Again, the same variety might show either resistance or susceptibility when subjected to different environmental conditions, even though the phosphorus-potassium ratio might be much the same. A few figures giving the phosphorus and potassium contents of cane juices from the islands of Kauai and Oahu will be of interest in this connection. Table 4 gives these data.

TABLE 4.—*The relation to brown stripe infection of the amounts of phosphorus and potassium in the juices of adjoining canes, January, 1931.*

Variety of cane, age, etc.	Degree of infection	Content of cane juice, p.p.m.	
		Phosphorus	Potassium
From Kauai			
Grove Farm, Field 1:			
POJ 2878, 7 months old	Light	26	2,180
H 109, 7 months old	Medium	19	860
Grove Farm, Field 4:			
POJ 36, 4 months old	Medium	98	3,640
H 109, 4 months old	Heavy	70	1,920
Kipu, Field 4:			
POJ 36	Heavy	54	1,885
POJ 36	Heavy	48	1,267
POJ 36	Heavy	55	1,510
Kipu, Field 8:			
POJ 36	Light	130	2,928
From Oahu			
Waialua Agr. Co. Field Helemano 2A:			
H 109, small stalks	Heavy	18	845
H 109, medium stalks	Heavy	16	765
H 109, large stalks	Heavy	11	700
Manoa 198	Disease free	10	1,300
Kohala 107	Disease free	24	1,250
POJ 36	Disease free	62	1,445
Kohala 202	Disease free	78	2,745

There are marked varietal differences shown in Table 4, both in susceptibility to disease and also in the phosphorus and potassium content of the juices. In any direct comparison, as on Grove Farm, for instance, where the varieties were adjoining and growing under the same conditions, the resistant variety is higher in both phosphorus and potassium than the susceptible one. This is usually true of the P. O. J. varieties when directly compared with H 109. If one variety is compared under varying conditions, as for example, P. O. J. 36 at Grove Farm and at Kipu, there is a general rise in the amount of both phosphorus and potassium in the juice as the variety becomes more resistant. In this case it is more nearly true for phosphorus than for potassium. At Grove Farm this apparently does not hold for H 109, but the age differences may be an explanation for this discrepancy. With the varieties tested from the Waialua Agricultural Company on Oahu, the correlation with disease resistance holds more truly for potassium than for phosphorus. From the meager data available, obtained as it has been under such varying conditions, it is impossible to make a definite statement as to the relation of phosphorus and potassium to brown stripe infection. The data indicate, however, that the amounts of phosphorus or potassium assimilated by the plant, their balance with each other, or their balance with the nitrogen assimilated may be among the leading factors which determine whether a cane will be susceptible or resistant to brown stripe.

The amount of phosphorus assimilated by the host plant has a direct influence on the growth and development of the brown stripe organism. There are indications that if sufficient phosphorus is assimilated by the cane plant, it has an inhibiting effect on the sporulation of *Helminthosporium stenospilum*, and that if the quantity is sufficiently large, sporulation may be prevented almost entirely. This factor alone is very important, but when operating in conjunction with added resistance of the plant, there seems some hope for the control of this disease by the proper regulation of the nutritional balance.

The exact significance of varietal variations in the phosphorus or potassium content of cane juice is not known. It may indicate that one variety is able to take up more of these elements from the soil than another, or, that one variety is better able than another to grow normally by the use of less of these elements in its organic synthesis, thus leaving more phosphorus or potassium soluble in the juice. Data from Ayers (1) indicate that perhaps either of these conditions may be true, depending on the cane variety and the plant nutrient in question. The P. O. J. varieties usually take up more potassium from the soil, and, at the same time, have more in the juice, showing them to be better feeders on potassium. With phosphorus this is not generally true, probably because phosphorus is synthesized into organic form. Indications are that H 109 may actually take more phosphorus from the soil, and, at the same time, contain less in the juice than P. O. J. 2878. This would seem to indicate that H 109 requires more phosphorus in organic synthesis than P. O. J. 2878, leaving less mineral phosphorus in the juice. This may be, in part, an explanation as to why this variety is generally more susceptible to brown stripe than the P. O. J. varieties.

CONCLUSIONS

In conclusion, it may not be out of place to say a word on the relation of soil conditions to varietal performance. In the selection of a variety for highest production under any set of soil conditions, it is very important to know something as to its response in relation to disease resistance, growth, and quality of juice produced under those conditions. Recent methods for studying these relations give promise of helping to answer some of these questions. Results obtained by these methods point to the fact that any variety will give its greatest production under conditions where its nutrition is properly balanced in respect to nitrogen, phosphorus, and potassium, and it is generally known that all varieties are not the same in their requirements.

SUMMARY

A chemical study of cane juice and of soil conditions under which the cane is produced seems to indicate that there is a correlation between readily available plant nutrients and susceptibility to some cane diseases in Hawaii. This correlation may be either positive or negative, depending upon the factors in question.

Indications seem to point to growth failure as a *Pythium* root-rot, induced by an unbalanced nutrition in which low phosphorus and high mineral nitrogen are more or less outstanding. This disorder seems to have been on the increase during the history of the sugar industry in Hawaii.

Eye spot damage is usually associated with high mineral nitrogen and perhaps low potassium, but more especially with the former. The greatest damage is done by the "runner" and not so much by the immediate lesion.

Brown stripe appears associated with low mineral assimilation by the cane. It may be low phosphorus, low potassium, or both; or it may be associated with an unbalanced condition of phosphorus and potassium with nitrogen. Evidence seems to indicate that the assimilation of sufficient phosphorus and potassium in a balanced relation is a great aid in minimizing the danger from this disease. Resistant varieties, as a rule, are either better feeders on the phosphorus and potassium of the soil, or are capable of making normal growth by the use of less of these nutrients in their metabolism, thus leaving more of them in solution in the juice.

LITERATURE CITED

1. AYERS, A. Feeding habits of H 109 and P.O.J. 2878. Hawaii Sugar Planters' Assoc. Progress of Work. July, 1931.
2. BARNUM, C. C. Relative resistance and susceptibility of Hawaiian and introduced cane varieties to eye spot and brown stripe diseases. Hawaiian Planters' Record, 34 : 117 –134. 1930.
3. CARPENTER, C. W. Notes on *Pythium* root-rot. Hawaiian Planters' Record, 34 : 83–98. 1930.
4. HECK, A. FLOYD. The relation of molasses to the micro-biological activity in soil. Hawaiian Planters' Record, 34 : 301–306. 1930.
5. MARTIN, J. P. Diseases, malformations and blemishes of sugar cane in Hawaii. Hawaiian Planters' Record, 35 : 129–134. 1931.
6. PETTINGER, N. A. The expressed sap of corn plants as an indicator of nutrient needs. Jour. Agr. Res., 43 : 95–119. 1931.

EFFECT OF BOVINE DIGESTION AND OF MANURE STORAGE ON THE VIABILITY OF WEED SEEDS[1]

F. W. Atkeson, H. W. Hulbert, and T. R. Warren[2]

Annual losses caused by weeds have been estimated at 100 million dollars for the United States and 2 million dollars for the state of Idaho (1).[3] Weed control is a very serious problem in the seed-growing sections of Idaho, as seed production has become one of the most important agricultural industries in the state. The screenings resulting from the cleaning of alfalfa and clover seed alone amount to over a million pounds yearly. Many dairymen have become interested in utilizing these screenings as a feed for dairy cows because they are a waste product, low in price and high in protein. These screenings, however, are composed primarily of weed seeds, which raises the question as to whether or not such feeds can be utilized without special preparation and still not infest the farms with weeds through the spreading of manure.

The purpose of this experiment was to determine whether or not the spreading of manure over fields caused weed infestation, especially when feeds containing large quantities of weed seeds were fed. Viability of weed seeds as affected by the digestion process of cattle was studied to determine possible weed infestation when manure was hauled direct from the stable to the fields. Likewise, the viability of weed seeds in manure which had been stored for several months was studied to measure the combined effect of the digestion process and manure storage.

In discussing this problem Henry and Morrison (5) state, "Unground screenings will never be used by farmers who seek to keep their land free from noxious weeds, for many such seeds will pass through the animals uninjured and be carried to the field in the manure. Finely ground screenings are free from this objection."

Ayers, Hulbert, and Ahlson (1) state, "On the average farm many weed seeds are fed to animals in the various feeds, and often they are not greatly injured by passage through the digestive tracts. In the seed districts of Idaho, screenings from small seeded legumes are being fed to livestock with considerable success. Thus the danger of placing large numbers of weed seeds back on the land is increased."

Hills and Jones (6) as early as 1907 called attention to the large number of weed seeds found in some feeds. They reported 129 million weed seeds per ton in one sample of molasses feed. In later reports Hills and associates (7, 9) emphasized this problem. Attention was called to one sample of flax feed which was supposed to contain some ground weed seed, but analysis showed over one-fifth of the feed, or 400 pounds per ton, to be whole weed seeds that grew well. Weed seeds, particularly the small, hard-coated ones, are not digested by cattle or horses, according to Hills and associates (6, 8).

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[2] Dairy Husbandman, Agronomist, and Assistant Dairy Husbandman, respectively. The authors wish to acknowledge the assistance of D. B. Fales and L. H. Hempleman, students in the Department of Dairy Husbandry, in conducting these trials.

[3] Reference by number is to "Literature Cited," p. 397.

Korsmo (10) conducted a test to determine the effect of passage through the digestive tracts of horses, cows, and hogs on the vitality of weed seeds. His results indicated that cattle were less efficient than either horses or hogs in devitalizing weed seeds. Germination of the six weeds studied, after passing through cattle, varied from 2.2 to 90.4%.

Milne (11), while conducting experiments on pure-culture plats, noticed that crushed wheat grains and other seeds fed to cattle, especially just before seeding time, were a source of danger to the purity of the test. He found that 20.5% of these larger seeds germinated.

Beach (2) fed a Jersey cow flax feed which contained over 20% of apparently unground weed seeds. The percentage germination obtained on the weed seeds taken from 2 grams of the feed before feeding was 26.4. After passing through the cow the germination of seeds found in an ounce of washed feces was 4 and 5% for two trials. He also reports very little germination from selected broken or injured seeds either before or after passing through the cow. From these results he reasons that weed seeds in feeds after passing through the cow may be a potent source of weed dissemination. Weed seeds sorted from this feed were buried more than half way down in a 100-ton silo when it was filled in October. When the seeds were taken out in December, laboratory tests showed that heat, fermemtation, and pressure of the silage did not inhibit germination.

Fitch and Zahnley (3) report that some weed seeds actually show better germination after being soaked for months in silage juice. Some samples after being buried in silage for 3 years showed good germination. Goss (4) found that the germination of weed seeds was less affected when the seeds were buried in the earth at various depths for periods of years than was the germination of cereals and legumes used for human food.

Oswald (12) stored seeds in piles of cow and horse manure for 6 months and obtained no germination when he took them out. He concluded that there is no danger of distributing weed seeds by scattering manure which has been stored in piles for 6 months. When the seeds were left in the manure only 1 month, germination tests showed no growth, but the seeds were more firm and less easily crushed than when left in the manure 6 months. He concluded that there is very little danger of weed infestation by spreading manure over fields if the manure has been stored 1 month. He also fed 21 different varieties of seeds to cattle. Each sample fed contained 2,000 seeds. An average germination of 12.8% was obtained after the seeds had passed through the digestive tract. Included in the list were wheat, oats, rye, barley, and corn. All of these were relatively large seeds and were quite low in germination after exposure to the digestion process. If these grains were eliminated from the list of seeds, leaving only weed seeds and cultivated legumes and grasses, the weighted average germination before feeding was calculated to be 71%; and after passing through the cattle, 18%. He considered these conditions analogous to spreading manure on fields when taken direct from the stables. Only 2.3% of the seeds fed to animals germinated under controlled conditions similar to hauling manure direct from the stables, spreading it, and plowing it under. An average of 3.1% of the seeds fed to animals germinated when manure was left on the field in a manner similar to droppings by animals.

PLAN OF EXPERIMENT

A preliminary experiment was conducted with five common weed seeds. The following year the experiment was repeated, using 18 samples of weed seeds. Seeds of various characteristics as to size, structure, type of seed coat, etc., were represented. The seeds studied are listed in Tables 1 and 2. Germination tests were made on each sample of seed immediately preceding feeding.

In the first year's trial six Holstein cows were used. In the second year's trial the first group of seeds was tested with four Holstein and four Jersey cows. As no variation in results attributable to difference in breeds was found, only Holstein cows were used for the remainder of the experiment. All the cows produced about 1¼ pounds of butterfat daily. During the first year's trial the cows were fed alfalfa hay, apple pomace, and a grain mixture; while in the second year's trial only alfalfa hay and a grain mixture were fed. Each cow was fed 1 quart of weed seed with her grain ration for two consecutive feedings, night and morning. In the first trial only one kind of seed was fed at a time, but in the second trial each cow was fed a quart mixture of two seeds of quite different characteristics. Because of the large amount of seed fed it was possible to notice some differences in palatability of the seeds even though they were fed as part of the grain mixture. Mustard, dodder, curled dock, and lamb's quarter were the least palatable. It was necessary to pour diluted molasses over the grain containing mustard or lamb's quarter in order to get the cows to eat it. After passing through the digestive tract the seeds were recovered by washing and decanting through a series of sieves. The seeds were then dried and tested for germination.

A 3-gallon sample of the feces from each cow was obtained for each seed studied and mixed with wheat straw to make the mixture comparable to stable manure. The samples were then stored in galvanized buckets for 3 months. At the end of this period the seeds were recovered from the manure and tested for germination to determine the effect of storage in manure on the viability of the different kinds. All germination tests were run on blotters in duplicate. Fifteen days were allowed for germination.

The time required for any noticeable amount of seeds to pass through the cow was about 42 hours, but seeds continued to come through up to 97 hours, about 4 days. Samples of all lots of seeds fed were obtained at 47 hours after feeding.

Since pigweed, during the first year, proved to be the least affected by the digestion process, during the second trial additional samples of this seed were recovered at 59, 73, and 97 hours. In addition to the samples taken at 47 hours, samples of lamb's quarter, cow cockle, curled dock, and alfalfa were taken at 59 hours.

DISCUSSION OF RESULTS

Results of germination tests on all seeds studied before and after passage through the digestive tract are presented in Tables 1 and 2.

In general the softer coated seeds were reduced in vitality by passage through the digestive tract much more than were the harder coated ones. This probably was due primarily to the penetration of the digestive juices into the germ, resulting in its destruction. Some softer coated seeds were affected by mastication. Many of the wild oat seeds recovered were badly broken. No seeds of burdock, broad leaf plantain, or of the two lots of cheat were identified in the feces. This may possibly have been due to mastication, but smaller amounts of each of these seeds were fed than of the other species, and they may have escaped notice. Even in the case of harder coated seeds many of the seed coats were removed or broken open during the digestion process. Although under the conditions of this experiment seeds may have germinated after passage through the digestive tract, undoubtedly in many instances the vitality of these plants would be weakened to such an extent that they would die even if spread directly upon the land.

Considerable variation was found in the germination percentage of the different species before digestion. This would be expected because of the great differences in the characteristics of the seeds used and the variety of sources of supply. Undoubtedly the vitality of the original sample would have some influence on the reduction in vitality attributable to passage through the digestive tract.

Results of the second year's trial check fairly well with those of the first year on the five species of weed seeds used both seasons. Of the 19 samples, representing 13 different species, studied during the two trials, reduction in germination due to the digestion process was more than 90% in 6 samples and 80% or more in 11 samples. Two samples of Russian thistle and two of tumbling mustard were reduced more than 95% in germination. Results with wild oats were equally as good considering the large number of broken seeds found. Yellow sweet clover, broad leaf plantain, and alfalfa, all showed relatively high germination before feeding and reductions of 80% or more due to digestion. The percentage reduction was fairly high for dodder and fanweed, but the original germination was quite low. Green foxtail, lamb's quarter, curled dock, rough pigweed, and cow cockle were much less affected by the digestion process, ranking in about the order listed as to resistance.

Although in several instances different samples representing the same species checked quite closely, the differences found in some cases indicate that greatly varying results might be obtained on additional samples, especially with certain seeds.

TABLE 1.—*Germination tests on weed seeds before and after passing through the digestive tract of cattle and after three months storage in manure, first year's trial.*

Name of plant	Germination before feeding %	Germination after 47 hours digestion %	Decrease after 47 hours %	Germination after 47 hours digestion plus storage in manure %	Decrease due to manure storage %	Decrease due to manure storage and digestion combined %
Rough pigweed, *Amaranthus retroflexus*, L.	63.0	19.00	70	7.5	61	88
Cow cockle, *Saponaria vaccaria*, L.	4.5	0.75	83	Not tested	Not tested	Not tested
Wild oats, *Avena fatua*, L.	43.0	0.25	99	Not tested	Not tested	Not tested
Tumbling mustard, *Sisymbrium altissimum*, L.	76.0	0.50	99	Not tested	Not tested	Not tested
Russian thistle, *Salsola pestifer*, Nels.	50.0	1.25	97	Not tested	Not tested	Not tested

TABLE 2.—*Germination tests on weed seeds before and after passing through the digestive tract of cattle and after three months storage in manure, second year's trial.*

Name of plant	Germination before feeding %	Germination after 47 hours digestion %	Decrease after 47 hours digestion %	Germination after 59 hours digestion %	Germination after 73 hours digestion %	Germination after 97 hours digestion %	Germination after 47 hours digestion plus storage in manure %	Decrease due to manure storage %	Decrease due to manure storage and digestion combined %
Rough pigweed, *Amaranthus retroflexus*, L. (southern Idaho)	98	36.0	63	29	4	3	11.5	68	88
Rough pigweed, *Amaranthus retroflexus*, L. (northern Idaho)	63	61.0	3	—	—	—	10.0	84	84
Curled dock, *Rumex crispus*, L.	95	58.0	39	28	—	—	3.0*	95	97

Lamb's quarter, *Chenopodium album*, L.	70	58.0	17	46	—	—	22.0	62	69
Cow cockle, *Saponaria vaccaria*, L.	98	35.0	64	24	—	—	2.5	93	97
Alfalfa, *Medicago sativa*, L.	86	17.0	80	18	—	—	80.0	371†	7
Yellow sweet clover, *Melilotus officinalis*, L.	92	7.0	92	—	—	—	0	100	100
Buckhorn, *Plantago lanceolata*, L.	94	16.0	83	—	—	—	0	100	100
Green foxtail, *Setaria vividis*, Beauv.	21	19.5	7	—	—	—	0	100	100
Fanweed, *Thlaspi arvense*, L.	17	2.5	85	—	—	—	0	100	100
Dodder, *Cuscuta planiflora*, Tenore	7	1.7	76	—	—	—	0	100	100
Wild oats, *Avena fatua*, L.	74	10.0	86	—	—	—	0‡	100	100
Tumbling mustard, *Sisymbrium altissimum*, L.	53	2.0	96	—	—	—	0	100	100
Russian thistle, *Salsola pes--tifer*, Nels.	18	0.5	97	—	—	—	0	100	100
Common burdock, *Arctium minus*, Bernh.	No seeds recovered after passage through the digestive tract; possibly disintegrated by digestion process beyond recognition								
Broad leaf plantin, *Plantago major*. L.	No seeds recovered after passage through the digestive tract; possibly disintegrated by digestion process beyond recognition								
Cheat, *Bromus secalinus*, L.	No seeds recovered after passage through the digestive tract; possibly disintegrated by digestion process beyond recognition								
Cheat, *Bromus secalinus*, L.	No seeds recovered after passage through the digestive tract; possibly disintegrated by digestion process beyond recognition								

*Only 39 seeds. †Percentage increase. ‡Only 25 seeds.

The longer seeds remain in the digestive tract, the greater seems to be the reduction in germination. Of the five species tested at 59 hours, all but alfalfa showed considerably lower germination than at 47 hours. One sample of rough pigweed with an original germination of 98% showed 36% germination after being in the digestive tract 47 hours, 29% after 59 hours, 4% after 73 hours, and 3% after 97 hours.

Sixteen samples of seed were recovered after passage through the digestive tract and then stored in manure for 3 months. Of the 10 samples showing less than 20% germination after the digestive process, all but one, alfalfa, were completely devitalized after storage in manure. These two processes devitalized three samples of rough pigweed 84% or better; and lamb's quarter, the most resistant of any seed studied, contained 22% viable seeds, or a reduction in germination of 69%. After passing through the digestive tract and being stored in manure, alfalfa showed only 7% reduction in germination from the original test before feeding.

In actual practice even better results might be obtained because of the heat generated in large piles of manure. Very little heat was generated in the small samples used in this experiment. It seems worthy of emphasis that the germination tests reported on seeds, both after passing through the digestive tract and after storage in manure, are in percentage of seeds recovered. What percentage of seeds were disintegrated beyond recognition is not known. Therefore, considering the large number of seeds fed, the germination percentage as reported after digestion may be higher than would be the case if the germination were reported on the basis of percentage of original number of seeds fed that still germinated after digestion. This assumption is supported by the fact that in the case of broad leaf plantain, burdock, and two samples of cheat no seeds were recovered after digestion.

From the data presented it is not possible to measure the relative devitalizing effect of digestion and of storage in manure. Only weed seeds carried into the manure through feeds consumed were considered. What effect storage in manure would have on weed seeds from such sources as straw used for bedding, barn sweepings, waste hay, etc., was not measured. It would appear, however, from the results of this experiment and the report of Oswald (12) that many of the weed seeds from such sources would be considerably devitalized.

CONCLUSIONS

The results of this experiment indicate that the digestion processes of cattle greatly reduce the percentage viability of most weed seeds under Idaho conditions, thereby tending to minimize manure as a source of weed infestation. However, the number of viable seeds, especially of some plants, after passing through the digestive tract makes manure a possible weed manace if feeds containing large numbers of weed seeds are fed. Storage of manure caused an additional reduction in percentage of viable seeds. Manure which has been stored 3 months could be scattered over fields with little chance of weed infestation so far as weed seeds consumed in feeds are concerned.

LITERATURE CITED

1. AYERS, JESSIE C., HULBERT, H. W., and AHLSON, C. B. Idaho weeds, how to know and control them. Ida. Agr. Ext. Div. Bul. 65. 1924.
2. BEACH, C. L. Viability of weed seeds in feeding stuffs. Vt. Agr. Exp. Sta. Bul. 138. 1908.
3. FITCH, J. B., and ZAHNLEY, J. W. Weeds used as silage. Kansas Industrialist, Manhattan, Kan. Nov. 4, 1931.
4. GOSS, W. L. The vitality of buried weed seeds. Jour. Agr. Res., 29 : 349–362. 1924.
5. HENRY, W. A., and MORRISON, F. B. Feeds and Feeding. Madison, Wis.: The Henry-Morrison Co. Ed. 18. 1923. (Page 161.)
6. HILLS, J. L., and JONES, C. H. Commercial feeding stuffs. Vt. Agr. Exp. Sta. Bul. 131. 1907.
7. ————, ————, and BENEDICT, P. A. Commercial feeding stuffs. Vt. Agr. Exp. Sta. Bul. 144. 1909.
8. ————, ————, ————. Commercial feeding stuffs, principles and practice of stock feeding. Vt. Agr. Exp. Sta. Bul. 152. 1910.
9. ————, ————, and CULTER, C. Commercial feeding stuffs. Vt. Agr. Exp. Sta. Bul. 133. 1908.
10. KORSMO, E. The viability of weed seeds after passing through the digestive tract of farm animals. Tidsskr Norske Lander, 18 : 223–230. 1911.
11. MILNE, D. Vitality of weed seeds passed by cattle. Agr. Jour., India, 10 : 353–369. 1915.
12. OSWALD, EDWARD INGRAM. The effect of animal digestion and fermentation of manure on the vitality of seeds. Md. Agr. Exp. Sta. Bul. 128. 1908.

THE REDFIELD TEPARY BEAN, AN EARLY MATURING VARIETY[1]

SAMUEL GARVER[2]

Certain annual plants have the capacity to adapt themselves rather rapidly over a period of years to changed environment as a result of natural selection within a heterogeneous or distinctly variable population. This characteristic is possessed by some plants to a greater degree than others. An outstanding example of such change in adaptation has occurred in a variety of the tepary bean (*Phaseolus acutifolius*, Gray, var. *latifolius*, Freem.) grown in the Redfield field experiments at Redfield, South Dakota.

The cultivated varieties of the tepary bean have been developed from one of the two distant forms of *Phaseolus acutifolius* which are native to the southwestern United States and to Mexico. Many varieties had been developed and grown for food by the Indians before the advent of the white man. Freeman collected 47 distinct varieties of teparies among the Indian tribes of Arizona and Mexico in 1910 and he first called attention to the possibilities of the species as a drought-resistant crop for the West and Southwest. A number of varieties of teparies are now grown to some extent in Arizona, New Mexico, Oklahoma, and west Texas as human food, as a hay plant, or as a cover crop.

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[1] Contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Washington, D. C. Received for publication September 11, 1933.

[2] Associate Agronomist.

The first planting at Redfield was made in 1914, and although plantings have been made each year since, with the exception of 1916, the bean did not appear to be promising for several years as only a small percentage of the seed matured. However, by 1920, as a result of planting each spring such seed as matured the preceding fall, an earlier maturing and more productive strain had been developed. In the years following 1920 plantings of the Redfield variety of tepary made from May 20 to 25 usually matured in about 110 days, being 14 to 18 days earlier than the unadapted Texas strain planted at the same time and under identical conditions. As it is believed that this early-maturing variety developed at Redfield has considerable agricultural value for portions of the northern Great Plains, a brief description of the bean and an account of the results of the tests appear timely.

DESCRIPTION

In appearance the cultivated form of tepary of which there are many varieties is quite different from the wild form. The Redfield tepary has been developed from the white-seeded variety produced in Texas. It differs from the parent stock mainly in earliness of maturity, though the seed usually has a slightly greenish cast instead of being pure white. It flowers continuously and often quite profusely from late July or early August until killed by frost. Seeds mature from late August until killing frost, at which time a few pods are always immature. Well-developed pods contain six to seven seeds. The size and plumpness of the seed vary with the seasonal condition and more particularly with the amount and distribution of the July and August rainfall. The number of seeds to the pound and the weight per bushel as compared with other beans are as follows:

	Number of seed to the pound	Weight per bushel, lbs.
Redfield tepary	3,012	66
Navy	2,663	63
Great Northern	1,702	56
Mandarin soybean	3,328	58

The differences in weight between Redfield tepary, navy, and Great Northern varieties appear to be due to the differences in size of seed. The specific gravity of the tepary, however, is apparently much greater than that of the soybeans.

COMPARATIVE YIELDS OF THE REDFIELD TEPARY (*Phaseolus acutifolius* var. *latifolius*), NAVY, AND GREAT NORTHERN BEANS (*Phaseolus vulgaris*), AND SOYBEANS (*Soja max*)

Based on the results of tests as given in Table 1, the effect of the changed environment was not appreciable until about 1920, since prior to that year the production of mature seed was comparatively low except during the longest growing seasons. Since that time, however, the change in maturity has been very apparent and the yields have been relatively high as compared with other beans. During the 18-year period, 1914 to 1932, the seed yields of teparies varied from 1.6 to 27.3 bushels to the acre. With the exception of the very dry season of 1926, the smallest yields were obtained during the first 5 years of test, 1914 to 1919, inclusive. Although the crop was favored by growing seasons longer than average in 1914 and 1915, only small amounts of well-matured seed were obtained. Severe midseason drouth in 1917 resulted in low yields. The 1918 plantings were injured by drouth and a killing frost on September 16 of that year prevented the maturing of seed. Yields were better in 1919, but not equal to soybeans. From 1920 to 1932, seed yields of the Redfield tepary exceeded those of all other varieties in 12 of 14 consecutive years, and excelled in the production of good mature seed in all years, except 1922 and 1927, when soybeans were more productive. It has shown greater heat and drouth resistance than the other varieties of beans, producing good crops in seasons when Navy and Great Northern beans failed almost completely, and has outyielded, by a considerable margin, the best varieties of soybeans over the same period. These results are indicative of the possible value of this crop for northern dry-farming conditions.

TABLE 1.—*Acre yields of Redfield tepary compared with those of Navy and Great Northern beans and soybeans at Redfield, South Dakota, 1914 to 1932, inclusive.*

Year*	Bushels per acre			
	Redfield tepary bean†	Navy bean	Great Northern bean	Mandarin soybean
1914	8.7	—	—	10.7
1915	10.2	—	—	10.2
1917	1.6	—	—	3.0
1918	2.5	2.8	—	5.4
1919	8.8	7.0	—	13.3
Average 1914–19	6.4			8.5
1920	24.7	9.6	13.9	19.3
1921	18.8	8.2	8.3	13.7
1922	12.0	5.7	9.2	13.2
1923	27.3	6.4	12.5	18.9
1924	17.4	12.9	15.8	13.7
1925	15.3	4.8	6.6	6.9
1926	10.1	4.5	6.9	5.0
1927	19.5	20.6	18.1	27.7
1928	16.8	3.4	4.7	8.9
1929	15.0	0.9	3.5	5.5
1930	18.1	1.1	1.5	6.9
1931	12.7	0.3	1.9	5.0
1932	16.3	2.0	4.3	10.0
Average 1920–32	17.2	6.2	8.2	11.9

*Sowing omitted in 1916.

†The Redfield tepary has been a gradual development resulting from several years of mass selection. It was not until 1920, however, that the characteristics were sufficiently distinctive to justify varietal recognition.

CAMPARISON OF REDFIELD AND A SOUTHERN VARIETY OF TEPARY

For the purpose of obtaining evidence of the apparent change that had taken place in maturity and productivity as a result of growing the tepary at Redfield, South Dakota, several seasons, seed obtained from Lubbock, Texas, was included in the test each year from 1923 to 1930, inclusive, except in 1927.

TABLE 2.—*Acre yields of the Redfield tepary compared with those of a Texas variety.*

Variety	Bushels per acre				
	1923	1924	1926	1928	Average
Redfield*...............	27.3	17.4	10.1	16.8	17.9
Texas T. S. 3306†........	12.9	14.1	6.0	6.4	9.8

*Variety developed at the Redfield Station since 1914.
†Seed received each year from the experiment station at Lubbock, Texas.

As is shown in Table 2, the average annual yield of the Redfield variety of tepary was 17.9 bushels to the acre, as compared with 9.8 bushels for the Texas tepary. Owing to the very poor stands of the Texas tepary in 1925, 1929, and 1930, yields for those years are not considered. The Texas variety was found to require from 14 to 18 days longer to mature than the Redfield variety in the years that frost was sufficiently delayed to permit full maturity, and the seed was inferior in grade to the Redfield tepary. Stands for the 4 years that yields were obtained averaged for the Redfield tepary 93% and for the Texas tepary 71%, the poor stands of the Texas variety being apparently due to the use of seed of low germination. The better stands of the Redfield variety, however, could not account for the decidedly higher yields since in seasons with a limited moisture supply uniformly thin stands even as low as 71% may be more productive than thick stands.

RELATION OF SEED YIELDS TO SEASONAL PRECIPITATION

Since seasonal precipitation has a direct bearing on yields of beans, an attempt has been made to show graphically in Fig. 1 such relationships for the years 1920 to 1932, inclusive. For most years of this period, owing to low subsoil moisture reserve, the beans have been dependent on seasonal precipitation. In 7 of the 13 years, the annual precipitation at this station was below normal and the accumulated deficiency for the period amounted to 10.52 inches.[3] Less than average seasonal precipitation occurred in 9 of the 13 years, with an accumulated deficiency of 14.04 inches. Lack of moisture during these years was generally accompanied by abnormally high temperatures in midseason and often high winds. The greatest average precipitation deficiencies occurred during the months of May, July, and August. As moisture is especially important during late July and early August when plants are in flower and seeds are setting, the shaded portion of the precipitation graphs are made to represent the total July and August rainfall.

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[3] 35-year average annual precipitation, 19.52 inches; 35-year average seasonal precipitation, 14.91 inches. Slight errors due to no records for February 1912, March 1913, and December 1921.

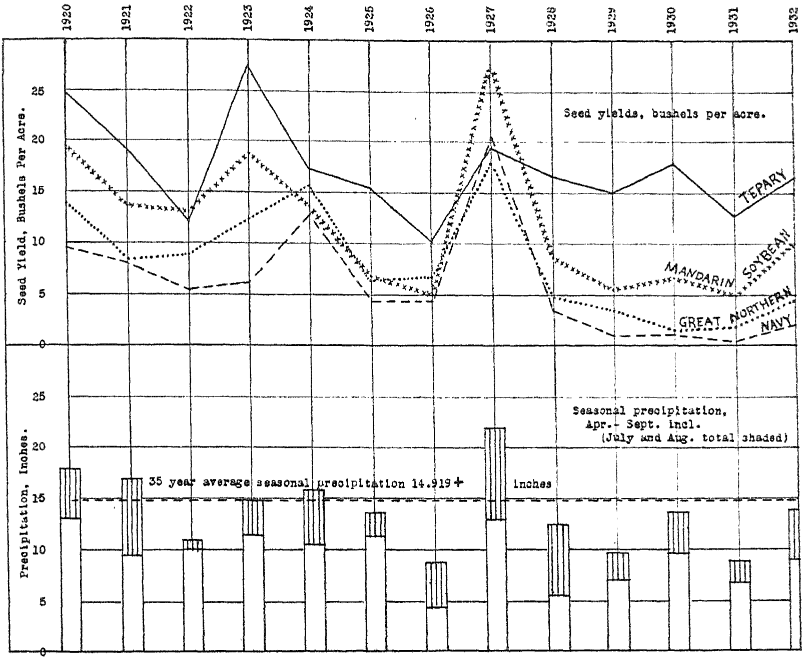

FIG. 1.—Comparative seed yields and seasonal precipitation for the years 1920 to 1932, inclusive.

Nonuniform stand, due to variable seed qualities and rodent and insect injuries, were the important factors tending to produce relative yield discrepancies. Temperature and wind in excess of normal greatly increased evaporation and when this was accompanied by a low subsoil moisture reserve, the drying out of the surface soil was rapid. In changing locations of tests from year to year, soil of slightly different character may have had pronounced effects on yields, especially during periods of drouth. Despite inopportune distribution of precipitation many years and other abnormal factors, the chart shows a direct relationship between seasonal precipitation and seed yields. The most marked exceptions occurred in 1922, 1923, 1924, and 1927.

Fairly satisfactory seed yields in 1922 were the result of precipitation decidedly in excess of normal in 1920 and 1921, and a total precipitation of 16.07 inches well distributed throughout the first 5 months of 1922. Only 0.93 inch of rainfall was received in July and August.

The importance of proper combinations of heat and opportune precipitation are shown in the yields of the Redfield tepary for 1923. There were no extremes of temperature and there was a total of 7.46

inches of well-distributed rainfall in June and July that produced an unusually large plant growth. The moderate temperatures and low rainfall in August and the first half of September seemed especially favorable for the filling and maturing of teparies, which gave the largest seed yield (27.3 bushels per acre) obtained during the 13-year period. Other bean varieties were injured by a lack of moisture in August.

In 1924, the cold wet spring and early summer caused an abnormally small plant growth and an unusual thinning by cutworms. Despite greater seasonal precipitation than in 1923, especially in July and August, teparies gave smaller yields. These are the only two consecutive years in which increased precipitation was accompanied by a markedly opposite effect on the seed yield of the tepary.

Navy and Great Northern beans and Mandarin soybeans made the greatest response to the heavy precipitation and cool growing season of 1927, and returned the largest yields in the 13-year period. The comparatively low seed yield of the tepary was probably due to having the poorest stands in a season when no advantages were derived from the wide spacing of plants.

That the advantages of teparies are most marked in dry, hot seasons is graphically shown for the five consecutive dry seasons of 1928, 1929, 1930, 1931, and 1932, when the yields over navy beans were from 13.4 to 17.0 bushels to the acre, over Great Northern beans 10.8 to 16.6 bushels, and over Mandarin soybeans 7.7 to 11.2 bushels. The very small seed yields of navy and Great Northern beans during these years were generally due to extreme heat and drouth in July and early August that caused the dropping of buds.

PESTS

Disease injuries to teparies have not been observed at this station. In cold springs, considerable reduction in stands has resulted from cutworms and gophers and in recent years the pheasant has destroyed emerging seedlings. Rabbits prefer soybeans and will destroy the stands while leaving adjoining plantings of tepary, navy, and Great Northern beans unmolested.

USES

The tepary is grown for human food, its uses being similar to those of the navy and Great Northern beans, the last-named being the most universally relished of the northern varieties, though individual tastes vary and some prefer other varieties, including tepary. It is important to soak the tepary at least 12 hours before cooking. In preparing equal quantities of the 1932 crop for baking, it was found that after soaking 12 hours, the volume of the Redfield tepary increased 150%, while the volume of navy beans increased 125%, indicating that the Redfield tepary fully equals the navy in volume increase. The Redfield tepary was also preceptibly firmer after cooking and gave a slightly stronger and less pleasant odor.

Because of the greater yields of other legume hay crops, such as alfalfa, clover, and field peas, it is not expected that teparies will be grown for hay or silage under northern dry-farming conditions, though they have been used to some extent as a hay and green manure crop in the Southwest. The straw is of some value as a feed for livestock.

SUMMARY

The Redfield tepary bean is a domesticated variety of wild bean utilized mainly as human food. Within the period 1914 to 1920 there was developed by mass selection from a Texas tepary T.S. 3306, a southern white variety, a new variety that matures at least 2 weeks earlier and which is also characterized by nearly white seeds of a greenish cast. The new variety is named Redfield.

Since 1920 the Redfield has been found more productive than navy or Great Northern bean (*P. vulgaris*), Mandarin soybean (*Soja max*), or a white variety of tepary from Texas (*Phaseolus acutifolius* var. *latifolius*). The best comparative yields have been obtained in seasons of extreme drouth and heat, when teparies set seed under the most adverse conditions even when the buds of navy and Great Northern beans dropped off without setting seed.

Despite inopportune precipitation and other abnormal factors in most years, a quite direct relationship between seasonal precipitation and seed yields has been apparent. Moderate temperatures and well-distributed rainfall in July and early August have been of the greatest benefit to beans.

STATISTICAL DETERMINATION OF BARLEY VARIETAL ADAPTATION[1]

F. R. Immer, H. K. Hayes, and LeRoy Powers[2]

Variety tests are standard experiments wherever agronomic investigations are being conducted. They are usually conducted at more than one locality in a given area for the purpose of obtaining information as to varietal adaptation. The questions that such an investigation should answer are (a) whether there are significant differences between yields of varieties; (b) whether there are significant differential responses between different varieties grown at the various stations, i.e., whether the relationship between varieties is the same at all stations; (c) whether the varieties respond differently in different years; (d) whether the varieties responded differently at certain stations in certain years; and (e) whether the varietal differences are of sufficient magnitude so that one variety may be expected to serve large portions of or the entire area included in the tests over a period of years. If differential responses are found it should be possible to determine the particular adaptation of given varieties in the places tested or years grown.

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[1] Contribution from the Division of Sugar Plant Investigations, U. S. Dept. of Agriculture and the Minnesota Agricultural Experiment Station, University Farm, St. Paul, Minn. Jour. Series paper No. 1210 of the Minnesota Agricultural Experiment Station. Received for publication August 31, 1933.

[2] Associate Geneticist, Division of Sugar Plant Investigations, U. S. Dept. of Agriculture and Statistical Advisor in the Minnesota Agricultural Experiment Station, and Chief of Division of Agronomy and Plant Genetics and Assistant Professor of Plant Genetics, respectively, in the Minnesota Agricultural Experiment Station. The writers wish to express their appreciation to J. W. Hopkins, Division of Biology and Agriculture, National Research Council, Ottawa, Canada, for his helpful criticisms of the manuscript.

This paper is essentially a methodology study and illustrates the application of the analysis of variance in an endeavor to obtain answers to the above questions. The statistical method used, known as the "analysis of variance," was developed by R. A. Fisher (1, 2).[3] In numerous papers he has not only developed the method on the mathematical side but has pointed out its application to agronomic problems as well.

The mechanics of the reduction of data by the analysis of variance has been discussed in numerous papers among which those by Fisher (1, 2), Fisher and Wishart (3), Goulden (4), and Wishart (6) may be mentioned as applying directly on the problems to be discussed here.

MATERIALS AND METHODS

The data considered in this paper deal with the yields, in bushels per acre, of 10 varieties of barley grown in 1/40 acre plats at University Farm, St. Paul, and at the five branch experiment stations located at Waseca, Morris, Crookston, Grand Rapids, and Duluth, Minnesota. The names applied to these five branch stations, namely, the southeast, west central, northwest, north central, and northeast experiment stations describe their location in the state fairly accurately. University Farm, St. Paul, is in east central Minnesota. The varieties were grown in three randomized blocks at each of these six stations during 1930 and 1931, different land being used each year of the test.

The names of the varieties and their Minnesota numbers are given below:

Variety	Minnesota No.	Variety	Minnesota No.
Manchuria	184	Manchuria x Smooth Awn	457
Glabron	445	Smooth Awn x Manchuria	462
Svansota	440	Peatland	452
Velvet	447	Svanhals x Lion	475
Trebi	448	Wisconsin No. 38	529

These are all standard varieties except Minn. Nos. 457, 462, and 475 which are selections from crosses and have, as yet, not been given a variety name. The standard varieties will be referred to by name and the unnamed crosses by number.

The analysis of variance consists of separating the total degrees of freedom and sums of squares into a number of portions due to known sources of variation, leaving a residual portion ascribable to unknown or uncontrollable causes and assigned to error. The mean square, or variance, is calculated from the sums of squares divided by the degrees of freedom. The significance of the difference between the different variances is determined by the "Z" test developed by Fisher (2).

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[3] Numbers in parenthesis refer to "Literature Cited," p. 419.

The total sum of squares is calculated from the formula $S(X-\bar{X})^2$, or expressed in more convenient form for calculation, $S(X^2) - S(X)\bar{X}$, where S indicates summation, X is any individual plat yield, and $\bar{X}$ is the mean yield of all plats. X_s, X_y, X_v, and X_b will be used to designate the total yields for a given station, year, variety, or block, respectively. Then, X_{sy} will be the total yield of all varieties grown at a given station in a given year, X_{vs} will be total yield of a given variety at a given station in all years, while X_{vys} is the total yield of a variety at a given station in a given year. The sum of squares for X_{vs} can be computed conveniently from $\frac{S(X_{vs}^2)}{6} - S(X)\bar{X}$. $S(X_{vs}^2)$ is divided by six since each variety was grown for 2 years and three plats were used in each trial, giving six plats in all. The rule is as follows: Add the squares of the yields under consideration, divide by the number of plats contained in each yield figure squared, and subtract the product of general total times general mean. The entire analysis is then kept on a single plat basis throughout.

The degrees of freedom are one less than the number of observations for each variable studied. The 10 varieties contribute 9 degrees of freedom, the six stations 5 degrees of freedom, and the 2 years 1 degree of freedom. The degrees of freedom for the interactions will be the product of the degrees of freedom for the separate variables. The degrees of freedom may be keyed out as follows:

Variation due to:	Degrees of freedom
Stations	5
Years	1
Stations x years	5
Varieties	9
Varieties x stations	45
Varieties x years	9
Varieties x stations x years	45
Blocks	24
Error	216
Total	359

The 24 degrees of freedom for blocks given above is made up of 2 degrees of freedom for blocks in general, 10 for interaction of blocks x stations, 2 for blocks x years, and 10 for blocks x stations x years. Since these 24 degrees of freedom are due to that part of the soil variation which is to be eliminated, they need not be separated into their component parts. The separation of the total degrees of freedom into the various components is extremely important. Once the degrees of freedom have been keyed out, the calculations to be made are indicated.

EXPERIMENTAL RESULTS

The yields, in bushels per acre, of these 10 varieties of barley grown in three randomized blocks, or replication series, at each of the six stations during each of 2 years are given in Table 1. The sums of the yields for the three plats of each variety in each test as well as the sum of the yields for each block are given in the marginal totals.

TABLE I.—*Yields in bushels per acre of 10 varieties of barley grown at six stations in each of 2 years.*

Block No.	Variety										Sum
	Manchuria	Glabron	Svansota	Velvet	Trebi	No. 457	No. 462	Peatland	No. 475	Wisconsin No. 38	
					University Farm 1931						
1	29.2	44.6	33.9	36.7	41.2	45.8	35.8	38.5	15.5	44.3	365.5
2	25.0	39.1	39.4	41.0	31.9	38.8	36.0	29.6	32.8	37.4	351.0
3	26.8	45.5	32.1	42.0	36.6	45.2	38.0	30.2	25.7	36.2	358.3
Sum	81.0	129.2	105.4	119.7	109.7	129.8	109.8	98.3	74.0	117.9	1,074.8
					University Farm 1932						
1	19.7	28.6	20.1	20.3	19.3	18.7	18.0	22.3	18.5	27.9	213.4
2	31.4	38.3	30.8	27.5	22.4	29.1	23.6	30.8	35.8	40.0	309.7
3	29.6	43.5	31.4	32.6	45.5	31.5	35.1	31.1	35.7	46.1	362.1
Sum	80.7	110.4	82.3	80.4	87.2	79.3	76.7	84.2	90.0	114.0	885.2
					Waseca 1931						
1	47.5	55.4	44.5	56.9	63.9	63.0	62.8	41.2	56.6	61.1	552.9
2	52.2	53.4	46.0	40.6	63.8	51.2	65.4	51.5	38.6	58.0	520.7
3	46.9	56.8	51.5	53.2	63.8	60.1	69.1	53.0	45.1	57.3	556.8
Sum	146.6	165.6	142.0	150.7	191.5	174.3	197.3	145.7	140.3	176.4	1,630.4
					Waseca 1932						
1	40.8	44.4	41.0	44.6	53.5	43.0	48.4	39.8	41.7	71.5	468.7
2	29.4	34.9	41.1	41.4	44.2	47.8	44.8	39.2	44.4	47.6	414.8
3	30.2	33.9	33.4	26.2	50.0	35.8	40.9	29.1	37.7	55.4	372.6
Sum	100.4	113.2	115.5	112.2	147.7	126.6	134.1	108.1	123.8	174.5	1,256.1

Morris 1931										
1	24.0	27.5	26.5	27.2	42.1	30.0	36.9	24.7	18.5	32.0	289.4
2	24.7	25.5	21.5	28.0	42.5	30.9	29.0	29.5	19.2	25.5	276.3
3	33.6	33.3	29.3	23.2	46.7	25.2	25.2	35.4	30.1	30.9	312.9
Sum	82.3	86.3	77.3	78.4	131.3	86.1	91.1	89.6	67.8	88.4	878.6
Morris 1932										
1	29.6	36.6	27.1	35.9	40.0	37.7	45.1	35.7	38.7	47.8	374.2
2	34.1	34.3	35.7	33.9	46.9	49.6	45.9	41.9	37.4	44.5	404.2
3	39.4	34.5	42.3	46.7	53.0	43.3	50.0	52.0	56.6	49.2	467.0
Sum	103.1	105.4	105.1	116.5	139.9	130.6	141.0	129.6	132.7	141.5	1,245.4
Crookston 1931										
1	38.4	39.5	41.2	33.4	53.3	46.1	46.1	40.5	44.2	44.8	427.5
2	37.8	37.6	39.6	49.7	40.2	50.8	56.4	37.1	42.8	58.9	450.9
3	43.6	37.3	40.6	40.9	47.3	40.1	43.2	47.2	45.3	45.9	431.4
Sum	119.8	114.4	121.4	124.0	140.8	137.0	145.7	124.8	132.3	149.6	1,309.8
Crookston 1932										
1	34.7	28.8	17.7	29.8	49.0	39.7	27.7	27.7	34.4	43.0	332.5
2	29.1	28.7	20.4	38.4	42.1	31.2	27.3	27.6	33.1	32.7	310.6
3	35.1	21.0	23.8	28.0	34.4	32.1	36.6	20.4	28.9	32.0	292.3
Sum	98.9	78.5	61.9	96.2	125.5	103.0	91.6	75.7	96.4	107.7	935.4
Grand Rapids 1931										
1	34.3	21.4	30.0	22.5	38.3	30.6	23.1	35.8	15.7	31.5	283.2
2	26.9	30.2	23.7	19.9	29.0	30.6	24.8	39.4	22.1	36.1	282.7
3	37.7	35.8	35.3	26.7	22.0	35.3	26.9	28.9	21.3	35.8	305.7
Sum	98.9	87.4	89.0	69.1	89.3	96.5	74.8	104.1	59.1	103.4	871.6

TABLE I.—*Concluded.*

Block No.	Variety										Sum
	Manchuria	Glabron	Svansota	Velvet	Trebi	No. 457	No. 462	Peatland	No. 475	Wisconsin No. 38	
					Grand Rapids 1932						
1	20.2	13.2	12.2	24.5	15.3	14.8	19.6	27.6	18.6	19.0	185.0
2	30.2	20.5	23.7	41.6	17.2	25.4	25.8	30.0	14.3	18.4	247.1
3	16.0	9.6	14.0	30.6	29.4	18.2	14.3	22.7	12.8	24.6	192.2
Sum	66.4	43.3	49.9	96.7	61.9	58.4	59.7	80.3	45.7	62.0	624.3
					Duluth 1931						
1	28.8	30.7	33.2	22.2	36.6	27.1	26.1	35.2	27.6	29.6	297.1
2	26.6	32.9	23.9	28.0	32.8	41.2	31.4	28.1	44.6	30.3	319.8
3	31.5	25.4	20.0	28.7	32.4	32.5	26.8	32.7	27.0	34.9	291.9
Sum	86.9	89.0	77.1	78.9	101.8	100.8	84.3	96.0	99.2	94.8	908.8
					Duluth 1932						
1	22.8	32.5	21.0	33.6	32.0	25.1	27.7	39.0	30.8	30.5	295.0
2	26.1	26.4	22.0	17.6	30.2	19.4	19.1	27.7	22.8	35.8	247.1
3	18.8	18.7	23.7	16.2	29.6	23.6	20.7	27.4	28.5	21.7	228.9
Sum	67.7	77.6	66.7	67.4	91.8	68.1	67.5	94.1	82.1	88.0	771.0

The sum of squares for total variation is calculated first. Squaring the 360 individual plat yields in Table 1 and adding gives 472,540.26. The general sum of the yields of the 360 plats is 12,391.4 bushels. The general mean is 12,391.4÷360 or 34.42055 ---- bushels. The product of general sum times general mean is 426,518.8721. The sum of squares for total, $S(X^2) - S(X)\bar{X}$, will be 472,540.26 — 426,518.8721 or 46,021.3879.

To obtain the sum of squares for stations, years, and the interaction of stations x years, it is necessary to combine the data in Table 1 in order to give the total yields for each station during each year. Such are given in Table 2. It is to be noted that all the data in the entire test are used in this and in all subsequent tables.

TABLE 2.—*Total yields of all varieties at each station and in each year.*

Station	Year		Total
	1931	1932	
Univ. Farm	1,074.8	885.2	1,960.0
Waseca	1,630.4	1,256.1	2,886.5
Morris	878.6	1,245.4	2,124.0
Crookston	1,309.8	935.4	2,245.2
Grand Rapids	871.6	624.3	1,495.9
Duluth	908.8	771.0	1,679.8
Total	6,674.0	5,717.4	12,391.4

The sum of squares for stations is calculated from the station totals. This is given by $\frac{S(X_s)^2}{60} - S(X)\bar{X}$, since each station total is made up of the yields of 60 plats. Squaring the six totals and adding, i.e., $(1960.0)^2 + (2886.5)^2 + (2124.0)^2 + (2245.2)^2 + (1495.9)^2 + (1679.8)^2$, gives 26,785,226.14. Dividing by 60 and subtracting the product of general total times general mean, 426,518.8721, leaves 19,901.5636 as the sum of squares for stations (for 5 degrees of freedom).

The sum of squares for years will be given by $\frac{S(X_y)^2}{180} - S(X)\bar{X}$, since 180 plats contribute to each yearly total. Numerically this amounts to $\frac{(6674.0)^2 + (5717.4)^2}{180} - 426{,}518.8721 = 2{,}541.8988$ (for 1 degree of freedom).

The interaction of stations x years is considered next. Squaring the 12 individual totals in Table 2, summing, dividing by 30, and subtracting the product of general total times general mean, i.e., $\frac{S(X_{sy})^2}{30} - S(X)\bar{X}$, leaves 28,750.1032 (for these 11 degrees of freedom). Subtracting the sums of squares for stations (19,901.5636) and years (2,541.8988) leaves 6,306.6408 as the sum of squares for the interaction (for 5 degrees of freedom). The sum of squares for such a first order interaction is the remainder after subtracting the sums of squares for the two margin totals from the total sum of squares in the table.

To compute the sum of squares due to varieties and the interaction of varieties x stations, the yields given in Table 1 are combined on the basis of total yield of each variety at each station and are given in Table 3. The mean yields for the sum of six plats will be used in a later discussion.

The sum of squares for varieties is calculated from the margin total for varieties. Thus, $\frac{S(X_v)^2}{36} - S(X)\bar{X} = 3{,}157.7168$, is the sum of squares for varieties (for 9 degrees of freedom).

The sum of squares for interaction of varieties x stations is considered next, i.e., $\frac{S(X_{vs})^2}{6} - S(X)\bar{X} = 26{,}676.5679$ (for 59 degrees of freedom). From this is subtracted the sums of squares for varieties (3,157.7168) and for stations (19,901.5636) to leave 3,617.2875 as the sum of squares for this interaction (for 45 degrees of freedom).

In order to calculate the sums of squares for the interaction of varieties x years the data in Table 1 are combined and given in Table 4 on the basis of total yield of each variety, at all stations, for each of the 2 years. The means for totals of 18 plats will be used later.

The sums of squares for varieties and years have already been obtained. Only the interaction remains, i.e., $\frac{S(X_{vy})^2}{18} - S(X)\bar{X} =$ 6,328.9390 (for 19 degrees of freedom). Subtracting the sums of square for varieties and for years leaves 629.3234 as the sum of squares for the interaction of varieties x years (for 9 degrees of freedom).

The second order interaction of varieties x stations x years is calculated from the yields of the individual varieties at each station in each year. These yields are given in Table 1 as the sums of the yields of three plats of each variety at each station in each of 2 years. The sum of squares for these 120 three-plat totals, $\frac{S(X_{vys})^2}{3} - S(X)\bar{X}$, is 38,129.8012 (for 119 degrees of freedom). From this must be subtracted the sums of squares for varieties, years, and stations computed separately and the interaction of varieties x years, varieties x stations, and of stations x years, thus:

Variation due to	Degrees of freedom	Sums of squares
Total	119	38,129.8012
Varieties	9	3,157.7168
Years	1	2,541.8988
Stations	5	19,901.5636
Varieties x years	9	629.3234
Varieties x stations	45	3,617.2875
Stations x years	5	6,306.6408

Subtracting the sums of squares of the other causes of variability from the total (for the 119 degrees of freedom) and making the same subtraction for degrees of freedom, leaves 1,975.3703 for the sum of squares for the interaction of varieties x stations x years for 45 degrees of freedom.

TABLE 3.—*Total yield of each variety for 2 years at each of six stations.*

Station	Variety										Total	Mean
	Manchuria	Glabron	Svansota	Velvet	Trebi	No. 457	No. 462	Peatland	No. 475	Wisconsin No. 38		
Univ. Farm	161.7	239.6	187.7	200.1	196.9	209.1	186.5	182.5	164.0	231.9	1,960.0	196.0
Waseca	247.0	278.8	257.5	262.9	339.2	300.9	331.4	253.8	264.1	350.9	2,886.5	288.6
Morris	185.4	191.7	182.4	194.9	271.2	216.7	232.1	219.2	200.5	229.9	2,124.0	212.4
Crookston	218.7	192.9	183.3	220.2	266.3	240.0	237.3	200.5	228.7	257.3	2,245.2	224.5
Grand Rapids	165.3	130.7	138.9	165.8	151.2	154.9	134.5	184.4	104.8	165.4	1,495.9	149.6
Duluth	154.6	166.6	143.8	146.3	193.6	168.9	151.8	190.1	181.3	182.8	1,679.8	168.0
Total	1,132.7	1,200.3	1,093.6	1,190.2	1,418.4	1,290.5	1,273.6	1,230.5	1,143.4	1,418.2	12,391.4	
Mean	188.8	200.1	182.3	198.4	236.4	215.1	212.3	205.1	190.6	236.4		206.5

TABLE 4.—*Total yield of each variety at six stations in each of 2 years.*

Year	Variety										Total	Mean
	Manchuria	Glabron	Svansota	Velvet	Trebi	No. 457	No. 462	Peatland	No. 475	Wisconsin No. 38		
1931	615.5	671.9	612.2	620.8	764.4	724.5	703.0	658.5	572.7	730.5	6,674.0	667.4
1932	517.2	528.4	481.4	569.4	654.0	566.0	570.6	572.0	570.7	687.7	5,717.4	571.7
Total	1,132.7	1,200.3	1,093.6	1,190.2	1,418.4	1,290.5	1,273.6	1,230.5	1,143.4	1,418.2	12,391.4	
Mean	566.4	600.2	546.8	595.1	709.2	645.2	636.8	615.2	571.7	709.1		619.6

The sum of squares due to blocks is determined next. This is obtained by first calculating the sum of squares for the margin totals for blocks in each station in each year in Table 1, there being 3 x 12 or 36 such totals made up of the yields of 10 plats each. Thus, $\frac{S(X_{bsy})^2}{10} - S(X)\bar{X}$ gives 31,613.0719 as this sum of squares (for 35 degrees of freedom). From this must be subtracted the sum of squares for stations, years, and the interaction of stations x years. The sum of these three was given as $\frac{S(X_{sy})^2}{30} - S(X)\bar{X}$ calculated from the 12 totals in Table 2 or 28,750.1032 (for 11 degrees of freedom). Subtracting this from 31,613.0719 leaves 2,862.9687 as the sum of squares for blocks (2 degrees of freedom) and the interaction of blocks x stations (10 degrees of freedom), blocks x years (2 degrees of freedom), and blocks x stations x years (10 degrees of freedom). Since the variation due to blocks alone and in combination with stations and years is simply calculated in order to remove the controlled element of soil heterogeneity the sum of squares for these 24 degrees of freedom need not be separated into its components.

The residual error alone remains. Adding the different elements of the total sum of squares already calculated and subtracting from the total leaves 5,028.6180 as the sum of squares due to error (for 216 degrees of freedom). The final analysis is now carried through in Table 5.

TABLE 5.—*Analysis of variance of yield.*

Variation due to	Degrees of freedom	Sum of squares	Mean square	Standard deviation	½ $\log_e$ of mean square	Z†
Stations.....	5	19,901.5636	3,980.3127	——	4.1446	2.5708
Years.......	1	2,541.8988	2,541.8988	——	3.9204	2.3466
Stations x years.....	5	6,306.6408	1,261.3282	——	3.5698	1.9960
Varieties....	9	3,157.7168	350.8574	——	2.9302	1.3564
Varieties x stations...	45	3,617.2875	80.3842	8.9657	2.1934	.6196
Varieties x years.....	9	629.3234	69.9248	8.3621	2.1237	.5499
Varieties x stations x years.....	45	1,975.3703	43.8971	——	1.8910	.3172
Blocks*.....	24	2,862.9687	119.2904	——	2.3909	.8171
Error.......	216	5,028.6180	23.2806	4.8250	1.5738	——
Total.....	359	46,021.3879				

*Made up of blocks alone and interaction of blocks with stations and years.
†For comparing the different mean squares with mean square for error.

The mean square column is obtained by dividing the sums of squares by the appropriate degrees of freedom. The standard deviation of a single plat is the square root of mean square.

Z is one-half the difference between the natural, or Naperian, logarithms of the different mean squares and the mean square for error. For example, the value of Z opposite variation due to varieties would be ½ ($\log_e$ 350.8574 — $\log_e$ 23.2806) = (2.9302 — 1.5738) = 1.3564. The other values of Z are calculated in a similar manner.

Turning to Fisher's table of Z (2), where n_1 is the degrees of freedom for the larger variance and n_2 the degrees for the smaller, it is noted that all values of Z given exceed the 1% point, and it is concluded that the chances are less than 1 in 100 that these mean squares are due to errors of random sampling.

The station and year comparisons are of interest only insofar as they demonstrate the range of yield in the different stations and years. The mean square due to blocks was highly significant, demonstrating that it has been worth while to plan the experiment in such a way that a certain part of soil variability could be controlled and eliminated in the calculations.

The mean square for varieties was highly significant, indicating that the average yields of these varieties in all tests were significantly different. Since the standard deviation of a single plat was 4.8250 bushels, the standard error of the mean of 36 plats would be 4.8250 $\div \sqrt{36}$, or 0.8042 bushel. The standard error of the difference between two such means would be 0.8042 $\sqrt{2}$ or 1.1373 bushel. Instead of comparing mean yields it might be more convenient to compare total yields. The standard error of the difference between two 36-plat totals would be 4.8250 $\sqrt{36}\ \sqrt{2}$, or 40.9415 bushels. In Table 6 are given the total yields of the varieties for all tests, of 36 plats each, the mean yield per plat, and the appropriate standard errors of the differences. The varieties are listed in order of yield from left to right.

Trebi and Wisconsin No. 38 were the two highest yielding varieties in these tests and gave significant increases in yield over all other varieties. No. 457, No. 402, and Peatland were in a slightly lower yield group with yield differences which did not reach twice the standard error of the difference. The differences in yield between Glabron and Velvet could not be said to have been significantly lower than Peatland, although numerically so. No. 475, Manchuria, and Svansota were in the lowest group for yield.

Having established the significance of yield differences for the average of all tests, it will be in order to determine next which variety or varieties were particularly adapted to certain stations. Since the mean square for interaction of varieties x stations, in Table 5, has been shown to exceed the mean square for error significantly it is apparent that some varieties reacted in a differential manner in certain locations. The residual error may now be used to determine which varieties were differential in response in given stations. The total yield of each variety for the 2-year period at each station, given in Table 3, is a convenient summation of data to use in determining which varieties gave differential responses.

The determination of the particular adaptation of certain varieties at the separate stations may be accomplished by calculation of the appropriate cross differences. For example, the yield of Manchuria at University Farm, minus the average yield of Manchuria at the other five stations, minus the yield of Glabron at University Farm, plus the average yield of Glabron at the other five stations may be used to determine whether the relative responses of these two varieties at University Farm were significantly different from the average responses at the other five stations.

In Table 7 are given the differences in yield of the sums of six plats (three plats in each of 2 years) for each variety from the average yield of the same variety at the other five stations, with a uniform correction being made for the average difference between all varieties in the station in question and the average of these varieties at the other five stations. These differences, then, express the magnitude of the increase of each variety at each station over the yields at the other five stations apart from the general increase or decrease of that station over the others. Plus deviations indicate a response more favorable than the average for the particular comparison at that station and negative values indicate that the variety was less well adapted.

It is of some interest to note that of the 22 deviations in excess of 20.0 bushels 6 are found at Waseca and 6 at Grand Rapids. The cross differences between varieties referred to previously can be obtained by getting the differences between any two deviations within any given station in Table 7. The error for these cross differences would be the standard error of the difference between two differences. The standard error of a single total of six plats would be $4.8250 \sqrt{6}$, or 11.8188. The standard error of the difference between one such total and the average of five others would be $\sqrt{(11.8188^2 + \frac{(11.8188)^2}{5}}$ or 12.9468. The standard error of the difference between two such differences is $12.9468 \sqrt{2}$, or 18.3095. Cross differences in excess of 2 x 18.3095 or 36.6 may be judged to be significant.

Thus Glabron gave a plus difference of 60.1 at University Farm, while Trebi was —34.8. The difference would be 60.1 + 34.8 or 94.9. This cross difference is certainly significant and a differential response is clearly indicated. This illustrates the manner in which the significance of such differential responses may be determined. Glabron seems to be particularly adapted to University Farm. Trebi, No. 462, and Wis. No. 38 seem to be particularly adapted to Waseca. Trebi was well adapted to conditions at Morris, while the cross differences involving all other comparisons omitting Trebi, at this station, failed to reach the minimum level of significance needed to demonstrate differential responses.

Peatland, a variety particularly adapted to peat soils, was the highest yielding variety at Grand Rapids and responded in a differential manner compared with all other varieties giving negative deviations.

No. 457 was one of the better yielding varieties, yielding more on the average than all others except Trebi and Wis. No. 38. It seems to have responded in a very uniform manner in all places. On this basis it seems well adapted to all localities.

TABLE 6.—*Total and mean yield of 36 plats of each variety.*

Yield	Variety										Standard error of difference
	Trebi	Wisconsin No. 38	No. 457	No. 462	Peatland	Glabron	Velvet	No. 475	Manchuria	Svansota	
Total	1,418.4	1,418.2	1,290.5	1,273.6	1,230.5	1,200.3	1,190.2	1,143.4	1,132.7	1,093.6	40.9
Mean	39.40	39.39	35.85	35.38	34.18	33.34	33.06	31.76	31.46	30.38	1.14

TABLE 7.—*Deviations of yields of six plats of the varieties at a given station from the average yield of the same variety at the other five stations, minus the difference between the average yields of all varieties for that station and the average yield of all varieties at the other five stations.*

Station	Variety									
	Manchuria	Glabron	Svansota	Velvet	Trebi	No. 457	No. 462	Peatland	No. 470	Wisconsin No. 38
Univ. Farm....	—19.9	60.1	19.1	14.7	—34.8	5.4	—18.3	—14.5	—19.3	7.2
Waseca.......	—28.6	—4.0	—8.2	—21.1	24.9	4.5	44.5	—40.0	—10.3	38.9
Morris........	—11.2	—17.1	—6.9	—11.3	34.7	—5.2	16.7	9.8	4.8	—14.9
Crookston.....	14.3	—30.2	—20.4	4.6	14.3	8.3	8.4	—27.1	24.2	3.5
Grand Rapids..	40.1	—14.9	16.3	29.2	—33.9	—3.9	—25.0	43.5	—34.6	—16.9
Duluth........	5.2	6.1	0	—16.3	—5.2	—9.2	—26.4	28.2	35.1	—18.1

The interaction of varieties x years can be studied in a similar manner. Cross differences can be obtained between the responses of any two varieties in each of the 2 years 1931 and 1932. The differences between the yields of 18 plats of each variety (see Table 4) in 1931 and 1932 were obtained by subtracting the yield in 1932 from that obtained in 1931, as follows:

Variety	Difference	Variety	Difference
Manchuria	98.3	No. 457	158.5
Glabron	143.5	No. 462	132.4
Svansota	130.8	Peatland	86.5
Velvet	51.4	No. 475	2.0
Trebi	110.4	Wisc. No. 38	42.8

The standard error of the difference between two such differences would be $4.8250 \sqrt{18} \sqrt{2} \sqrt{2}$, or 40.94 bushels. Differences in excess of 81.9 may be judged significant. The average difference between all varieties in 1931 and 1932 was 95.7 bushels. The yield of No. 475 was relatively much greater in 1932 than in 1931. The same was true of Velvet and Wis. No. 38. The reactions of Wis. No. 38 and Glabron, Svansota, No. 457, and No 462 were differential in nature. Other comparisons may be made and the seasonal effect on the yielding ability of these varieties determined.

Since the mean squares for the interactions of varieties x stations, varieties x years, and varieties x stations x years significantly exceeded the mean square for the remainder error, the Z value exceeding the 1% point, it will be in order to compare next the variety mean square with the mean square for interaction of varieties x stations and varieties x years. For such comparisons Z is one-half the difference between the natural logarithms of the two mean squares being compared. Comparing variety mean square with that for interaction of varieties x station, Z will be $\frac{1}{2}$ ($\log_e 350.8574 - \log_e 80.3842$). In Table 5 this is seen to be $2.9302 - 2.1934$, or 0.7368. $Z = 0.7368$ exceeds the 1% point for $n_1 = 9$ and $n_2 = 45$ degrees of freedom, and it is concluded the variety mean square significantly exceeded the mean square for this interaction. A similar comparison reveals the fact that the variety mean square significantly exceeded the mean square for interaction of varieties x years, the value of $Z = 0.8065$ exceeding the 5% point but not the 1%.

The mean square for these two first order interactions are compared next with mean square for varieties x stations x years. The value of Z for the comparison of the first order interaction, varieties x stations, with that for varieties x stations x years ($Z = 0.3024$) exceeds the 5% point but not the 1%, while the Z value for varieties x years compared with the second order interaction fails to reach the 5% point of significance ($Z = 0.2327$).

A number of facts are now clearly revealed. Differences in response among these varieties were not independent of year or place grown or the special circumstance which made a given year favorable or unfavorable at particular places. The significantly greater mean square for varieties x stations than for error shows that for an average of 2 years the relative performance of these varieties was not the same at all stations. With mean square for varieties x years significantly greater than error it is apparent that the average performance of these varieties at all stations was not the same in both years. The significantly greater second order interaction than the remainder error demonstrates that the relative performance of these varieties at different stations were not the same in both years.

The significantly higher mean square for varieties than mean square for interaction of varieties x stations and varieties x years show that varietal performance generally was consistent enough to demonstrate that some varieties were the best in these places in most years and that in these years some varieties were the best in most places. Further, the fact that the interaction of varieties x stations exceeds the second order interaction indicates that the differential responses of these varieties at the various stations were sufficiently similar in the 2 years to suggest that some differential responses may be permanent features of these localities. Insofar as these six stations constitute a random sample of conditions to be found over the entire state and that these 2 years are a random sample of weather conditions to be encountered in future years, general recommendations may be drawn up for the entire state with reasonable assurance that the variety or varieties recommended will prove to be consistently superior in most places of the state and in most years. Unless the mean square for varieties exceeds significantly the mean square for interaction of varieties x stations no general recommendations can be made for the entire state. In like manner, unless variety mean square exceeds significantly the mean square for varieties x years, we have no assurance that the varieties recommended will consistently prove superior in subsequent years.

The errors of field plat trials are due, to a great extent, to soil heterogeneity, which can be overcome to a considerable extent by replication and the use of plats of the most desirable size. In these studies this uncontrolled error is represented by the standard deviation for error of a single plat trial of 4.8250 bushels (see Table 5). As each variety was tested in 36 plats, the standard deviation of a difference would be $(4.8250 \div \sqrt{36}) \sqrt{2}$, or 1.14 bushels. A difference between any two varieties of 2 x 1.14 bushels, or 2.28, might be accepted as a significant difference under the conditions of the experiment and for the particular seasons and locations of the test. On this basis (see Table 6) Trebi and Wisconsin No. 38 were significantly better than any other varieties, while No. 457 was superior to all remaining varieties except No. 462 and Peatland.

Stadler (5) pointed out that the more serious error in determining the relative value of varieties or treatments is seasonal error. If one wishes to predict what may be expected in future trials, errors due to other conditions are of greater importance than those due to soil heterogeneity. For such a study the analysis of variance furnishes a convenient tool to use in drawing conclusions.

Considering the 2 years 1931 and 1932 as a random sample of years, the error to be used in making general recommendations in future years for the six stations at which the tests were conducted would be calculated from the standard error for interaction of varieties x years. The standard error of the difference between two means, calculated from the standard deviation for this interaction, would be $(8.3621 \div \sqrt{36}) \sqrt{2}$, or 1.97 bushels. This would allow Trebi, Wisconsin No. 38, and No. 457 to be placed in the high yield group with the others significantly lower in yield than Trebi or Wisconsin No. 38. A 2-year period is, of course, too short for conclusions to be drawn regarding seasonal effect. The calculations above are given to illustrate the appropriate method of analysis.

Considering the six stations at which these tests were made as random samples of all places in the state, the error to be used in making general recommendations for the entire state, irrespective of place grown, and assuming weather conditions were similar to those in 1931 and 1932, would be calculated from the standard deviation for interaction of varieties x stations (8.9657). The standard error of the difference between two means of 36 plats each would be $(8.9657 \div \sqrt{36}) \sqrt{2}$, or 2.11 bushels. On this basis the differences between the mean yields of Trebi, Wisconsin No. 38, and No. 457 (see Table 6) do not exceed twice this error and it cannot be concluded that the average yield of these varieties would have been significantly different in yield if grown over the entire state. Minn. No. 457, No. 462, Peatland, Glabron, and Velvet would belong to the same yield group.

Had the number of varieties tested been considerably greater it would have been of interest to separate the varieties into groups and determine whether groups could be found in which the yield differences were constant in place or in time. Such groupings of the varieties could be made also on the basis of specific diagnostic plant characters and a critical test made as to whether such characters condition constant yields in these places in the state, or in different years. With material of hybrid origin such groupings could be made also on the basis of parentage of the hybrids and the same type of comparison made. Such comparisons would be possible through a further, easy extension of the analysis of variance.

CONCLUSIONS

1. The analysis of variance was applied to a variety test with barley.

2. The method for calculating the variance of the different components of the total variation was illustrated.

3. The interactions of varieties x stations, varieties x years, and varieties x stations x years were significantly larger than error, indicating that some varieties reacted differently in different stations, in different years, and in certain stations in specific years.

4. The variety mean square significantly exceeded the mean squares for interaction of varieties x stations and varieties x years, showing that some varieties were significantly superior to others in spite of the differential responses.

LITERATURE CITED

1. FISHER, R. A. The arrangement of field experiments. Jour. Min. Agr., 33 : 503–513. 1926.
2. ———. Statistical Methods of Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1932.
3. ———, and WISHART, J. The arrangement of field experiments and the statistical reduction of the results. Tech. Comm. No. 10, Imp. Bur. Soil Sci. 1930.
4. GOULDEN, C. H. Modern methods of field experimentation. Sci. Agr., 11 : 681–701. 1931.
5. STADLER, L. J. Experimental error in field plot tests. Proc. Int. Conf. Plant Sci., 1 : 107–135. 1926.
6. WISHART, J. The analysis of variance illustrated in its application to a complex agricultural experiment on sugar beets. Archiv für Pflanzenbau, 5 : 561–584. 1931.

THE INFLUENCE OF MAGNESIUM DEFICIENCY ON PHOSPHATE ABSORPTION BY SOYBEANS[1]

L. G. WILLIS, J. R. PILAND, AND R. L. GAY[2]

There is abundant evidence that the assimilation of phosphates by plants is dependent on the supply of available calcium, but recently it has been suggested[3] that phosphates are not efficiently utilized where magnesium is deficient. If this be true, the matter of phosphate assimilation from the sandy soils of the South Atlantic states, where magnesium deficiency is frequently so acute as to produce definite symptoms in practically all cultivated crops, should be one of considerable concern.

Two of these soils, Durham sandy loam and Norfolk sandy loam, are in many instances so deficient in magnesium as to require fertilization with some magnesium compound, and the deficiency is almost invariably accentuated by the application of non-magnesian lime. An experiment including these two soils furnishes some data on the influence of calcium and magnesium on the absorption of phosphates.

Eight inches of the A horizon of these two soils underlaid by a foot of clean washed sand was placed in 24-inch glazed terra cotta drain tiles set in the ground in the open.

Pure calcite and pure dolomite, finely ground, were applied at the beginning of the experiment at rates indicated in Table 1. One of each of the lime treatments received potassium sulfate, one no potash, and one potassium chloride, and all the tiles received uniform amounts of mono-ammonium phosphate annually.

Soybeans were planted each year and cut just before maturity when the leaves began to be shed. Calcium, magnesium, and phosphorus were determined in samples of the air-dried plants. The data

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[2] Soil Chemist, Assistant Soil Chemist, and Fellow, respectively.

[3] KELLOG, CHAS. E. Magnesium—a possible key to the phosphorus problem in certain semi-arid soils. Jour. Amer. Soc. Agron., 31 : 494. 1931.

TABLE 1.—*Yield and lime, magnesia, and phosphoric acid content of soybean plants.*

Lime added	With potassium chloride				No potassium added				With potassium sulfate			
	Yield, grams	CaO %	MgO %	P_2O_5 %	Yield, grams	CaO %	MgO %	P_2O_5 %	Yield, grams	CaO %	MgO %	P_2O_5 %
					Durham Sandy Loam							
Calcite, 1 ton	147	1.22	0.182	0.48	186	1.43	0.227	0.41	98	1.15	0.249	0.33
Dolomite, 1 ton	152	1.08	0.650	0.35	125	0.93	0.654	0.38	125	0.84	0.590	0.36
None	123	0.72	0.192	0.31	96	0.90	0.244	0.35	98	0.88	0.223	0.32
Calcite, 5 tons	87	2.25	0.132	0.55	92	2.43	0.156	0.52	70	1.98	0.197	0.38
Dolomite, 5 tons	182	1.02	0.785	0.53	153	1.10	0.867	0.50	124	0.87	0.667	0.43
					Norfolk Sandy Loam							
Calcite, 1 ton	86	2.00	0.216	0.57	34	1.55	0.218	0.37	118	1.15	0.329	0.33
Dolomite, 1 ton	136	1.01	0.689	0.50	82	1.43	0.958	0.57	125	0.82	0.524	0.34
None	96	0.79	0.164	0.39	75	0.93	0.324	0.40	82	0.88	0.163	0.34
Calcite, 5 tons	72	2.68	0.097	0.47	120	3.10	0.157	0.39	93	2.16	0.182	0.48
Dolomite, 5 tons	145	1.11	0.718	0.37	143	1.63	0.856	0.38	144	1.11	0.751	0.47

given are taken from the analyses of the plants grown the third year.

There are six groups of results differing as to soil and potash fertilization. Since each of these is represented but once, the entire lot can be treated statistically as a unit. It is apparent, however, that the correlation between CaO and MgO is subject to bias in that the calcite treatments have been found to depress the solubility of the MgO in these soils, whereas the dolomite supplies both calcium and magnesium. The correlation of — .39 does not therefore establish any general principle, but it is useful in the interpretation of the other data.

The calcium and magnesium content of the plants is the resultant of two factors, *viz.*, the abundance of the supply and the influence of one on the absorption of the other. These factors cannot be segregated with the data given nor can the influence of these two elements on the absorption of phosphates be determined by simple correlations. A discussion of these is, therefore, of minor interest. For the CaO-P_2O_5 content of the plants, the simple correlation coefficient is + .42, while for MgO-P_2O_5 the coefficient is + .19. The former of these indicates a significant positive correlation, while the latter is of negligible significance.

The question is raised whether the low coefficient for MgO-P_2O_5 is a real value or only a reflection of the fact that with the calcite treatments generally the availability of the supply of magnesium is decreased.

A multiple correlation coefficient for CaO, MgO-P_2O_5 of + .57 suggests that the influence of the magnesium alone on P_2O_5 absorption is greater than is indicated by the simple correlation coefficients but does not give a quantitative expression of this influence. From the partial correlation coefficients for CaO-P_2O_5 (with MgO constant) of + .55 ± .09 and for MgO-P_2O_5 (with CaO constant) of + .43 ± .10, it is evident that within the limits of error of the data there is no significant difference between calcium and magnesium as regards their influence on the absorption of phosphates.

This is of particular significance since all the plants grown on the calcite treatments showed the symptoms characteristic of magnesium deficiency. An assumption that the phosphate content of the plants is an index of assimilation may not be valid since the phosphate might be absorbed in the presence of an abundant supply of calcium but not utilized when magnesium is deficient. This objection would entail a conclusion that the symptoms of magnesium deficiency are in fact a composite of magnesium and phosphate deficiency symptoms. There is no support for this idea in the results of experiments with tobacco[4] where the evidences of phosphate deficiency are quite distinct from those attributed to magnesium deficiency.

CONCLUSIONS

Calcium and magnesium are equally effective as agents influencing the absorption of phosphates by soybean plants.

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[4] McMurtrey, J. E., Jr. Distinctive effects of the deficiency of certain essential elements on the growth of tobacco plants in solution cultures. U. S. D. A. Tech. Bul. 340. 1933.

With an abundance of calcium a deficiency of magnesium does not limit the absorption of phosphates. The data do not indicate whether the phosphate absorbed under these conditions is efficiently utilized, but collateral evidence indicates that magnesium deficiency and phosphate deficiency have no mutual relation.

SUBSOIL MOISTURE AND CROP SEQUENCE IN RELATION TO ALFALFA PRODUCTION[1]

T. A. Kiesselbach, Arthur Anderson, and J. C. Russel[2]

In two previous papers,[3] the authors have shown the striking depletion of subsoil moisture as a result of the prolonged cropping of land to alfalfa with a consequent decline in yields, and also the relatively low yields of subsequent plantings of alfalfa through failure of the subsoil moisture to become restored under ordinary cropping conditions. This raised the questions whether the restoration of subsoil moisture might be profitably accelerated by special cultural treatments preliminary to reseeding with alfalfa, and whether some other legume might be grown to better advantage where the subsoil moisture has become depleted. Five years of additional data bearing on these questions have been secured, which it is the purpose of this paper to report. A state-wide survey of depletion and restoration under common cropping practices has been conducted cooperatively with the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. The results of this survey will be published in a subsequent paper.

PLAN OF EXPERIMENTS

The site of the experiments was field "B" of our previous study on the Experiment Station farm at Lincoln. Originally, this was a portion of a larger field that had been cropped solely to grain for about 50 years. In 1922 it was seeded to alfalfa, with the exception of a central strip 20 feet wide which was planted at the same time to brome grass. In the fall of 1927 it was found through soil moisture sampling that the alfalfa land had become thoroughly depleted of available moisture to depths well beyond the fifteenth foot. The land in brome grass, on the other hand, had lost very little moisture below the sixth foot. In the spring of 1928 the brome grass and part of the adjoining alfalfa were plowed and laid off into 1/20-acre plats for use in these investigations. Since previous experience with this land had indicated a high degree of uniformity, it was believed that the underlying principles might be established without replication of treatments, thereby holding down the labor involved.

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[1] Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Paper No. 143, Journal Series. Published with the approval of the Director. Received for publication August 31, 1933.

[2] Agronomists.

[3] Kiesselbach, T. A., and Anderson, A. Alfalfa investigations. Nebr. Agr. Exp. Sta. Res. Bul. 36 : 1–125. 1926.

Kiesselbach, T. A., Russel, J. C., and Anderson, A. The significance of subsoil moisture in alfalfa production. Jour. Amer. Soc. Agron., 21 : 241–268. 1929.

As a study of the rapidity with which the subsoil moisture might become restored following its depletion by alfalfa, some of the plats on the alfalfa sod have been cropped respectively to a 3-year grain rotation and to continuous corn, while other plats were clean summer fallowed from 1 to 5 years.

The comparative merits of alfalfa, sweet clover, and red clover on land formerly cropped to alfalfa were tested by seeding plats on the alfalfa sod to these respective crops in the spring of 1928. These same three crops were also sown on the alfalfa sod in the spring of 1929 and 1930 after 1 and 2 years of fallow, respectively. For the purpose of studying their moisture relations under more favorable conditions, these crops were likewise sown in the spring of 1928 on the brome sod land, which had never been cropped to alfalfa. In order to intensify their effects on soil moisture content and to provide a continuous comparison with alfalfa, the clovers were replanted each fall after having been handled as a biennial crop during their first 2 years. All of these plats and one remaining in alfalfa since 1922 were sampled for moisture content at foot intervals to a depth of 15 feet early in the spring of 1929 and each fall thereafter.

DESCRIPTION OF SOIL, PRECIPITATION, AND METHODS

SOIL

The soil where these tests were made is Carrington clay loam overlying Kansan Drift. The surface is mellow and quite receptive of moisture. The subsoil of the second and third feet is a tight clay not uncommon in soils of southeastern Nebraska. The deeper subsoil is a friable silt resembling loess to a depth of at least 35 feet except in the region of the fifteenth foot where pockets of coarse sand and gravel are sometimes encountered. The depth to the water table is about 100 feet. The tract has a uniform topography, with a slope of less than 1%.

PRECIPITATION

The precipitation for the period of this investigation is reported in Table 1. The monthly averages correspond rather closely to the Lincoln normal. The total precipitation for the 12-month periods between September 1 and August 31 is shown in the last column of the table as these intervals correspond most closely with the soil moisture records taken for the crop year. Since moisture received in rains of less than 0.5 inch is largely lost through direct evaporation, the percentage of the precipitation falling in daily amounts greater than this is shown in the lower part of the table.

SOIL MOISTURE SAMPLING AND SOIL CONSTANTS

Soil samples for moisture determinations were taken with steel tubes by foot sections to a depth of 15 feet. Sampling was done once each year near the close of the crop season, except the first year, 1928, when it was done early in the following spring. Since sampling on

TABLE 1.—*Annual and monthly precipitation during the 6-year period, 1927–32.**

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Jan. to Dec.	Annual Sept. to Aug.†
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1927	0.10	1.30	2.03	4.47	1.77	3.27	2.06	2.90	3.20	0.53	0.01	0.07	21.71	—
1928	0.05	0.73	0.49	1.26	2.27	4.19	5.17	3.08	2.90	2.63	3.13	0.01	25.91	21.05
1929	0.80	1.08	0.03	3.25	2.54	2.62	8.08	0.45	1.98	4.76	1.13	0.05	26.77	27.52
1930	0.84	0.28	0.51	2.90	3.47	2.91	1.24	4.24	1.90	0.51	3.19	0.14	22.13	24.31
1931	0.20	1.11	1.12	2.38	6.66	3.35	2.30	2.93	4.50	1.80	5.38	2.27	34.00	25.79
1932	1.55	0.95	0.47	1.37	3.33	5.23	4.90	5.57	1.87	1.76	0.03	0.78	27.81	37.32
Average	0.59	0.91	0.77	2.60	3.34	3.59	3.96	3.20	2.73	2.00	2.15	0.55	26.39	27.20
Normal	0.65	0.94	1.22	2.47	4.05	4.25	3.86	3.54	2.91	1.94	1.21	0.78	27.82	—
Percentage of Precipitation Recorded in Daily Amounts Greater than 0.5 Inch														
1927	0	77	75	39	38	68	68	50	92	0	0	0	60	—
1928	0	0	0	63	67	39	84	63	86	68	85	0	66	63
1929	0	0	0	23	82	94	89	0	34	55	0	0	59	71
1930	0	0	0	42	53	76	44	61	86	0	100	0	60	48
1931	0	60	0	34	88	92	87	65	82	34	50	91	69	74
1932	0	59	0	43	72	59	69	71	60	70	0	0	59	62

*The monthly and annual precipitation records were taken at the Experiment Station farm where the tests reported herein were conducted. The normal precipitation data are from the records of the Lincoln Station of the Nebraska Section, U. S. Weather Bureau.

†This period corresponds approximately to the crop year.

the various plats extended through a period of several days with rains occasionally intervening, no significance is to be attached to the moisture conditions in the first 2 feet as reported in the tables that follow. Likewise, to exclude seasonal effects, permanent storage should be considered as that below 5 feet in depth.

From two to four cores were taken per plat and moisture determined on each core separately. Replicate determinations usually differed by less than 1.5%, except in the lower portion of an advancing wet column. Since previous experience had shown a high degree of textural uniformity throughout the tract, moistures are compared directly instead of on the free-water basis as in the earlier paper. Hygroscopic coefficient and moisture equivalent determinations, however, are shown in Table 2 for interpretation of free-water contents and degree of wetness. The values reported in this table are based on five air-dried sets of single-core samples taken by foot sections to a depth of 15 feet. The ratios of moisture equivalents to hygroscopic coefficients and the approximate field carrying capacity as represented by 85% of the moisture equivalent are also included.

TABLE 2.—*Hygroscopic coefficients and moisture equivalents of foot sections of soil to a depth of 15 feet in the field under investigation.**

Depth of soil, feet	Hygroscopic coefficient	Moisture equivalent	Moist. equiv. ÷ hygr. coef.	Approximate field carrying capacity†
1	11.4	30.0	2.63	25.5
2	15.8	34.9	2.21	29.7
3	14.3	34.0	2.38	28.9
4	13.6	31.6	2.32	26.9
5	12.7	31.9	2.51	27.1
6	12.5	32.3	2.58	27.5
7	12.6	32.4	2.57	27.5
8	12.1	32.7	2.70	27.8
9	12.0	33.4	2.78	28.4
10	12.5	32.1	2.57	27.3
11	12.2	32.0	2.62	27.2
12	11.9	31.6	2.66	26.9
13	12.0	31.4	2.62	26.7
14	11.3	30.7	2.72	26.1
15	10.2	29.0	2.84	24.7

*Based on an average of the values obtained for five single-core samples so located as to represent the entire field.

†Moisture equivalent times 0.85. The factor is computed from the ratios of actual field moisture content to moisture equivalent for those foot sections of the fallow plats where obviously the soil had been restored to its complete retaining capacity. (See Table 3, column 15).

YIELD DETERMINATIONS

The forage yields of the various legumes were obtained by harvesting 10 randomly distributed 1/5000-acre quadrats from each plat at periods consistent with good farm practice. Plat margins were avoided in order to exclude border effects. In the tables that follow, yields are expressed on the 15% moisture basis. Alfalfa was cut three or four times and sweet clover and red clover twice each season.

No yields were obtained from the spring-seeded legumes in 1928, or in 1930 and 1931 on the 1- and 2-year fallow plats, respectively, as they were merely clipped their first year to control weeds and were not harvested for forage.

Satisfactory stands were maintained throughout the experiment and the growth of spring-planted sweet clover and red clover was fully normal. Seeded as fall annuals the clovers made practically normal top growth the following season though the root systems may not have attained the full development of 2-year plants.

SUBSOIL MOISTURE RESTORATION UNDER VARIOUS SYSTEMS OF FIELD MANAGEMENT

In eastern Nebraska it is the common procedure to follow alfalfa with a rotation of locally adapted cereals in order to realize maximum benefits from the increased soil productivity. Consequently, it is moisture replenishment under this system that should be given first consideration. Such studies have already been reported, but to obtain further information and to provide for direct comparison with other systems, an ordinary 3-year grain rotation of corn, oats, and winter wheat was included in these tests. The two special systems selected as most deserving of investigation in comparison with the grain rotation were continuous corn and summer fallow. Although the growing of corn more or less continuously has never been recommended, it is not an unusual practice. On the other hand, summer fallow is rarely practiced in Nebraska for the restoration of deep-seated subsoil moisture. It has been proposed by the Kansas Experiment Station[4] as a rapid method for the restoration of such moisture following a cropping to alfalfa. The data on subsoil moisture restoration under these three systems of management are reported in Tables 3 and 4.

GRAIN ROTATION

The initial water content in the fall of 1927 is shown in column 2 and the subsequent changes when cropped to corn, oats, and wheat in columns 3 to 6 of Table 3. The moisture conditions to a depth of 7 feet are shown graphically in Fig. 1. The seasonal and accumulative storage in inches is given in columns 3 and 4 of Table 4. Each year the annual rainfall was almost completely consumed (Table 3). As an average for the last 3-year period which embraces one complete rotation, the moisture content of the upper 5 feet was practically as low as the initial moisture content of the alfalfa sod in 1928 (Fig. 1). After 5 years the water stored below the fifth foot was only 0.13 inch (Table 4). These data fully corroborate our earlier conclusion that there appears little likelihood of any important increase in the subsoil moisture content occurring under a system of grain rotation where storage conditions are not more favorable than on the upland at Lincoln.

CONTINUOUS CORN

The changes in soil moisture when the land was cropped to continuous corn are shown in columns 7 to 10 of Table 3, and graphically

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[4] DULEY, F. L. The effect of alfalfa on soil moisture. Jour. Amer. Soc. Agron., 21 : 224–231. 1929.

TABLE 3.—*The comparative effects of a 3-year grain rotation, continuous corn, and continuous summer fallow upon the moisture content of soil that had been previously cropped to alfalfa during 6 years, 1922–27.*

Depth of soil, feet	Soil moisture content													
	Initial	After cropping to												
		Corn, oats, and winter wheat				Continuous corn				Summer fallow				
	1927 fall %	1929* spring %	1930 fall %	1931 fall %	1932 fall %	1929* spring %	1930 fall %	1931 fall %	1932 fall %	1929 spring %	1929 fall %	1930 fall %	1931 fall %	1932 fall %
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1	15.3	30.1	10.0	15.6	18.4	30.1	16.3	17.0	18.9	26.5	25.2	19.5	24.2	26.4
2	17.9	27.9	16.1	19.4	19.0	27.9	18.7	19.7	20.0	27.0	25.2	26.0	24.9	25.9
3	16.5	25.0	14.8	21.0	17.0	25.0	18.2	21.0	20.7	24.8	24.6	23.2	22.4	24.2
4	15.5	19.6	13.9	16.2	16.0	19.6	20.6	22.4	16.3	24.0	24.3	23.1	24.4	25.1
5	14.2	18.6	14.5	13.8	15.7	18.6	21.0	18.4	23.0	19.6	24.6	25.7	26.6	27.3
6	14.7	15.1	14.9	14.2	15.5	15.1	17.5	15.1	24.3	15.5	24.3	25.5	27.4	27.7
7	14.9	15.1	14.8	14.0	15.0	15.1	15.9	14.2	21.5	14.8	21.6	24.9	25.6	26.6
8	14.6	15.1	15.0	13.1	15.1	15.1	15.5	13.6	17.1	15.0	17.3	22.9	24.1	26.5
9	14.7	15.5	14.9	13.8	14.8	15.5	15.2	13.2	14.3	14.8	16.8	15.1	20.5	26.4
10	14.3	15.2	14.7	14.2	15.1	15.2	15.7	13.8	14.8	14.7	15.8	15.0	18.4	25.4
11	13.8	14.7	14.5	13.7	14.4	14.7	14.9	13.5	14.3	14.6	14.3	15.7	16.1	24.2
12	13.9	15.0	14.1	13.7	14.3	15.0	14.4	12.8	14.1	14.0	14.7	14.4	13.2	19.9
13	14.0	14.4	14.3	13.5	15.0	14.4	14.3	12.8	13.6	14.0	13.7	13.8	13.4	16.1
14	13.9	14.6	14.5	13.8	14.0	14.6	14.3	13.3	13.6	14.5	14.1	13.9	12.6	15.0
15	12.9	14.0	14.2	13.2	13.7	14.0	13.7	12.6	13.6	13.9	13.6	13.9	12.5	13.7
Averages of Successive 5-foot Depths														
1–5	15.9	24.2	13.9	17.2	17.2	24.2	19.0	19.7	19.8	24.4	24.8	23.5	24.5	25.8
6–10	14.6	15.2	14.9	13.9	15.1	15.2	16.0	14.0	18.4	15.0	19.2	20.7	23.2	26.5
11–15	13.7	14.5	14.3	13.6	14.3	14.5	14.3	13.0	13.8	14.2	14.1	14.3	13.6	17.8

*During the first season, the rotation and continuous corn plats were cropped and sampled as a single plat of corn.

TABLE 4.—*Seasonal and accumulative soil moisture storage under the conditions of a 3-year grain rotation, continuous corn, and continuous fallow on land previously cropped to alfalfa.*

Year*	Precipitation, inches	Amount of water in inches stored† under						Percentage of precipitation stored under continuous fallow	
		Grain rotation		Continuous corn		Continuous fallow			
		Upper 15 feet	Below 5th foot	Upper 15 feet	Below 5th foot	Upper 15 feet	Below 5th foot	Upper 15 feet	Below 5th foot
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Seasonal					
1928	29.52	7.03	0.07	7.03	0.07	7.22	0.13	24.4	0.4
1929	21.06	——	——	——	——	3.96	3.64	18.8	17.3
1930	14.97	—8.68	—0.04	—3.68	0.71	0.20	1.26	1.3	8.4
1931	26.93	2.67	—0.11	—0.38	—1.00	3.32	2.49	12.3	9.3
1932	35.19	0.23	0.21	3.40	3.34	6.72	5.65	19.1	16.0
				Accumulative					
1928	29.52	7.03	0.07	7.00	0.07	7.22	0.13	24.4	0.4
1929	50.58	——	——	——	——	11.18	3.77	22.1	7.4
1930	65.55	—1.65	0.03	3.35	0.78	11.38	5.03	17.4	7.7
1931	92.48	1.02	—0.08	2.97	—0.22	14.70	7.52	15.9	8.1
1932	127.67	1.25	0.13	6.37	3.12	21.42	13.17	16.8	10.3

*The seasonal precipitation and soil moisture data represent the interval between successive dates of sampling the fallow plats rather than the calendar year. These dates for the fallow were Oct. 1, 1927; April 17, 1929; Oct. 24, 1929; Aug. 5, 1930; July 21, 1931; and Aug. 10, 1932. The sampling on the cropped plats was also done on or near these dates. The plats in grain rotation and continuous corn were not sampled in the fall of 1929 and consequently their data for 1930 cover two seasons.

†These data are computed from the results reported in Table 3, using for the limiting depths of storage, as in Fig. 1, those foot sections into which definite penetration had occurred. Six per cent of moisture per foot of soil was considered equivalent to 1 inch of water as based on actual volume weight determinations to a depth of 10 feet.

in Fig. 1. The seasonal and accumulative storage in inches is shown in columns 5 and 6 of Table 4. At the end of 5 years of corn, the water stored below 5 feet amounted to 3.12 inches (Table 4). All of this increase occurred in the last year and may be associated with an unusually heavy fall and winter precipitation, coupled with the fact that the subsoil to a depth of 5 feet was already quite moist. It is probably to be viewed as largely permanent storage. Should such storage happen fortuitously once every 5 years, it would require about 50 years of continuous corn to restore completely the depleted subsoil moisture. Comparison of the moisture conditions under continuous corn with those of oats and wheat in the grain rotation seems to substantiate the rather generally accepted belief that the latter crops dry the soil more thoroughly and to greater depths than does corn. Continuous corn, however, is not recommended as a practical system of farming and the introduction of small grain into the cropping system along with corn will lower the rapidity of restoration.

SUMMER FALLOW

The moisture conditions at various dates during 5 years of continuous fallow following 6 years cropping to alfalfa are given in columns 11 to 15 of Table 3. The initial moisture conditions from which the amount of restoration is to be reckoned are shown in the second column of Table 3. The strictness with which individual percentages can be compared, and depths of penetration interpreted, can be estimated from the range of moisture contents at the lower depths where obviously no changes actually occurred. The progress

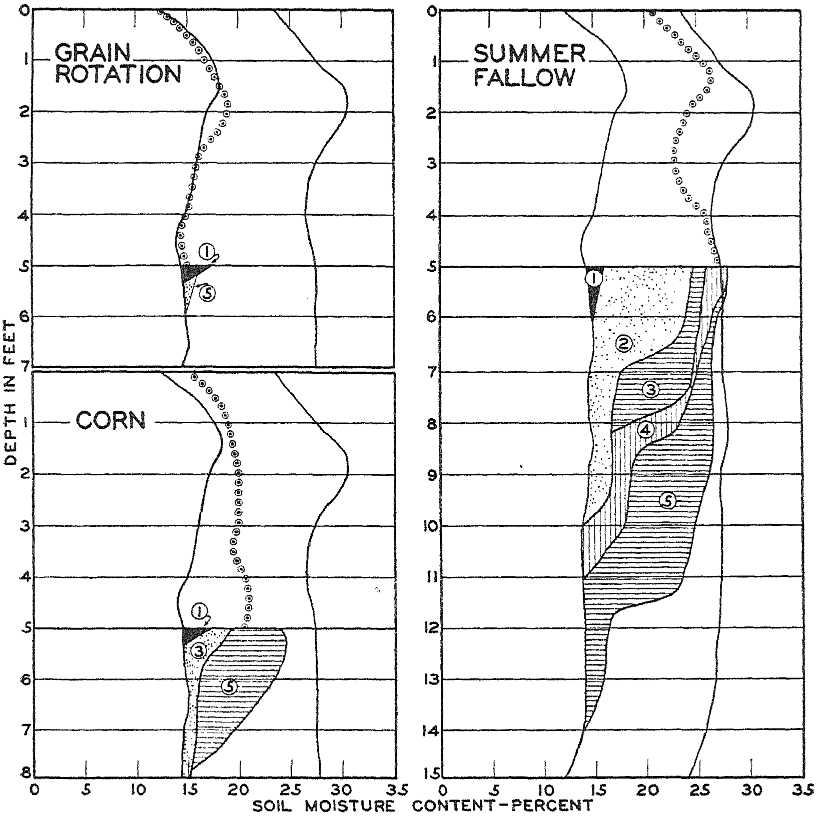

FIG. 1.—Restoration of subsoil moisture during 5 years (1928–1932) of (a) grain rotation (corn, oats, and winter wheat); (b) continuous corn; and (c) continuous summer fallow in land formerly cropped to alfalfa (1922–1927). The heavy solid line on the left in each diagram indicates the initial water content in the fall of 1927. The heavy solid line on the right indicates the calculated field carrying capacity. (See Table 2.) The line of circles above the 5-foot level shows the average moisture content of the last 3 years. The shaded areas indicate the amounts of storage below the 5-foot level during each of the five successive intervals (Nos. 1–5) between samplings. (See footnote, page 430.)

of restoration is shown graphically in Fig. 1,[5] and the quantities of water restored in terms of inches of rainfall in Table 4.

The maximum restoration was obtained during the first period, which extended from the fall of 1927 to the spring of 1929. This was the longest period of any and included considerable post-season precipitation which may account for the fact that almost as much restoration was obtained under corn as in the first year of fallow. On account of the extreme initial dryness very little restoration occurred in either case below the fifth foot. The second period from spring to fall in 1929 was one of abundant mid-summer and late fall rains and as a consequence restoration in the second year of fallow extended well into the seventh foot. The third period, as compared with the others, was very dry. Although continuous fallow gained some moisture below the fifth foot and the wet front made a definite advance into the ninth foot, the upper 5 feet lost so much moisture that the net gain for the season was negligible. It amounted to only 1.3% of the total precipitation as compared with 24.4 and 18.8% during the favorable periods preceding. During the fourth period restoration extended into the tenth foot. The fifth period was an unusually favorable one in total amount, character, and distribution of precipitation, and restoration in continuous summer fallow extended definitely into the twelfth foot. The total restoration in summer fallow during this period was not quite as large as during the first year, but, on account of the upper soil being well filled with water, the storage below the fifth foot was greater than in any other season.

At the end of 5 years of continuous summer fallow the more or less permanent storage below the fifth foot was 13.17 inches. The total

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[5] In the graphical representation of moisture conditions in Figs. 1 and 2, it has been assumed that the changes between foot sections are not abrupt as would be shown by simple bar graphs, but are gradual and therefore better shown by smooth curves. In preparing the curves, each moisture percentage has been systematically analyzed, with regard to conditions above and below, into a series of percentages so that the curves when fitted are consistently smooth, yet inclusive of the proper moisture contents. The actual moisture conditions in the profile may not have been precisely as the curves indicate. For example, in the lower portions of the summer fallow curves, a small increase in moisture content apparently occurred for several feet beyond the main wetted region. This is not actually the case but is largely the result of sampling by foot intervals and averaging the moisture contents of three or more cores in each instance. This may be illustrated by the individual moisture percentages of the following four cores which comprised the continuous fallow sample of 1932:

Foot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Core 1....	25.6	26.9	24.5	25.7	27.8	28.0	27.4	27.4	27.4	26.3	25.5	23.6	22.2	18.4	14.0
Core 2....	26.5	25.7	24.2	25.3	27.1	27.8	26.6	26.0	27.3	25.0	24.0	19.1	14.0	13.6	13.4
Core 3....	26.6	25.0	24.0	24.9	26.9	27.4	27.2	26.7	26.0	25.9	23.9	16.8	14.3	14.2	14.1
Core 4....	26.7	25.8	24.1	24.3	27.3	27.6	25.2	25.8	25.0	24.5	23.2	19.9	13.8	13.8	13.3
Average	26.4	25.9	24.2	25.1	27.3	27.7	26.6	26.5	26.4	25.4	24.2	19.9	16.1	15.0	13.7

It is to be observed that the moisture content is usually fairly uniform to within a foot, or probably a fractional foot of the region of initial dryness, but, in one core, penetration has extended about 2 feet further than in the other three. Thus on averaging there is an appearance of gradation of moisture throughout several feet.

storage was 21.42 inches or an average of 4.28 inches per year. From the data of our previous paper, it may be calculated that approximately 30 inches of water are required to put the subsoil from the sixth to the thirty-fifth foot inclusive into the moisture condition that obtained before it was first seeded to alfalfa in 1922 in addition to approximately 8 inches that are required to fill the upper 5 feet. On the basis of the annual rate above, complete restoration would require 9 to 10 years of continuous clean summer fallow. Considering that the reverse process of depletion would occur within a 5- or 6-year period of recropping to alfalfa, it is inconceivable that complete restoration by fallow could ever be a profitable practice. The rapidity with which the partial restoration of 1 and 2 years of fallow was utilized and the actual profitableness in terms of yield are shown in the two following sections of this paper.

UTILIZATION OF SUBSOIL MOISTURE BY ALFALFA, SWEET CLOVER, AND RED CLOVER

The utilization of subsoil moisture with respect to rate and depth of depletion was determined for alfalfa in our previous investigation. In this study two additional questions were involved, i. e., (1) the comparative degrees and depths to which moisture is exhausted by alfalfa and the two common alternative legumes, sweet and red clover; and (2) the expediency of restoring moisture by fallow prior to recropping to alfalfa. The former was studied under three sets of initial subsoil moisture conditions. These were extreme dryness resulting from 6 years previous cropping to alfalfa, relative moisture abundance as found in land that had never grown alfalfa, and the intermediate condition of partial restoration resulting from 1 and 2 years of fallow.

UTILIZATION OF MOISTURE FOLLOWING ALFALFA

The moisture conditions at various dates in the plats of alfalfa, sweet clover, and red clover planted on alfalfa sod where the subsoil was extremely dry are reported in Table 5. The initial water content in the fall of 1927 is shown in the second column.

Moisture percentages in the upper few feet show wide seasonal variations among the three legumes owing to weather conditions and stage of growth at sampling time, hence significance is attached only to moisture differences below the fifth foot. Below this level there has been no material change in moisture content throughout the 5-year period. In the red clover plat there was indication of a little moisture accumulation in the sixth foot, whereas in the alfalfa plat there was apparently a slight amount of further depletion below the fifth foot.[6] This depletion is better seen in Table 6 in which are reported the average total and free water contents of the lower 10 feet in the area replanted to alfalfa in 1928 and in that portion of the original field that was not plowed up. It is to be noted that at the end

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[6] The subsoil moisture contents of 1931 are slightly lower than those of 1932 in Table 5 and in every other table. The average discrepancy amounts to about 0.6 %. It is doubtless a systematic error associated either with the drying technic or the weather conditions that prevailed at time of sampling.

TABLE 5.—*The comparative effects of alfalfa, sweet clover, and red clover upon the moisture content of soil that had been previously cropped to alfalfa during the 6 years, 1922–27.*

Depth of soil, feet	Soil moisture content, per cent															
	Initial 1927 fall	After cropping to														
		Alfalfa					Sweet clover					Red clover				
		1929 spring	1929 fall	1930 fall	1931 fall	1932 fall	1929 spring	1929 fall	1930 fall	1931 fall	1932 fall	1929 spring	1929 fall	1930 fall	1931 fall	1932 fall
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
1	15.3	28.3	20.1	12.9	14.3	20.7	28.2	19.1	12.1	21.6	23.9	31.4	20.1	10.9	13.7	25.6
2	17.9	26.1	20.9	15.7	13.2	17.6	26.8	21.2	17.6	16.8	15.9	27.9	20.9	16.6	15.8	19.0
3	16.5	22.0	15.9	13.8	14.0	14.9	22.3	17.4	15.5	14.6	14.4	24.1	15.9	15.5	14.4	16.0
4	15.5	14.2	15.2	13.6	13.6	13.8	17.5	15.5	15.7	13.8	14.8	18.4	15.2	17.1	15.0	16.7
5	14.2	17.6	15.2	13.3	13.2	13.4	15.1	14.9	15.2	14.0	14.4	15.5	15.2	18.9	16.2	18.3
6	14.7	14.9	14.6	14.1	12.7	13.1	14.4	14.4	15.2	13.8	14.6	14.8	14.6	17.7	15.8	16.8
7	14.9	14.7	13.5	13.7	12.8	13.5	14.2	11.7	14.9	13.6	14.5	14.6	13.5	15.8	14.0	14.5
8	14.6	14.5	14.0	14.0	13.0	13.3	14.4	14.4	14.8	13.6	14.4	14.5	14.0	14.8	13.5	14.5
9	14.7	14.6	13.2	14.4	13.2	13.7	14.8	14.4	15.0	13.9	14.7	14.8	13.2	14.2	13.9	14.2
10	14.3	14.0	14.1	13.9	12.4	13.1	13.9	13.7	14.4	13.1	14.1	14.6	14.1	14.0	12.8	14.0
11	13.8	13.8	13.3	13.7	12.4	12.9	13.8	13.2	13.9	13.0	13.9	14.2	13.3	13.6	12.8	13.3
12	13.9	13.7	12.9	13.7	12.6	12.9	13.6	13.2	13.9	13.2	13.7	14.3	12.9	13.6	12.8	13.5
13	14.0	13.9	13.6	13.7	12.8	13.1	13.7	13.4	14.1	13.0	13.7	14.2	13.6	13.9	12.4	13.4
14	13.9	13.8	12.8	13.5	12.5	12.8	13.7	13.0	13.9	12.7	13.5	13.9	12.8	13.5	12.6	13.4
15	12.9	13.0	11.9	12.8	12.4	12.5	13.0	12.4	13.3	11.9	12.8	12.7	11.9	12.3	11.4	13.1
Averages of Successive 5-foot Depths																
1–5	15.9	21.6	17.5	13.9	13.7	16.1	22.0	17.6	15.2	16.2	16.7	23.5	17.5	15.8	15.0	19.1
6–10	14.6	14.5	13.9	14.0	12.8	13.3	14.3	13.7	14.9	13.6	14.5	14.7	13.9	15.3	14.0	14.8
11–15	13.7	13.6	12.9	13.5	12.5	12.8	13.6	13.0	13.8	12.8	13.5	13.9	12.9	13.4	12.4	13.3

of the 5-year period the subsoil was about 1% drier than in 1927 and had apparently attained this condition by 1929. It may be questioned whether this represents actual depletion or experimental error, but it is at least convincing of the completeness of moisture exhaustion.

TABLE 6.—*Comparative soil moisture content at various periods in a field of alfalfa first seeded in 1922 and in a portion of the same field reseeded after plowing in 1928.**

Time of sampling	Total water, per cent		Free water, per cent†	
	Original alfalfa	Reseeded alfalfa	Original alfalfa	Reseeded alfalfa
1927, fall	14.2	14.2	2.2	2.2
1929, spring	—	14.1	—	2.2
1929, fall	13.3	13.4	1.4	1.5
1930, fall	13.6	13.7	1.7	1.8
1931, fall	13.2	12.7	1.3	0.8
1932, fall	13.7	13.1	1.8	1.2
Average last 4 years	13.4	13.2	1.5	1.3

*The data are the average moisture contents for the sixth to fifteenth foot, inclusive.

†Total water minus the hygroscopic coefficient.

UTILIZATION OF MOISTURE IN NON-ALFALFA GROUND

The moisture conditions at various dates following the planting of alfalfa, sweet clover, and red clover in land which had never been cropped to alfalfa are shown in Table 7. The relatively abundant initial subsoil moisture in the brome grass land in the fall of 1927 is shown by the percentages in the second column. Both the initial and the final moisture conditions under each legume at the end of the fifth year are shown graphically in Fig. 2. For comparison, the moisture conditions in the adjacent 11-year-old alfalfa that was withheld from plowing at the beginning of these experiments, and the hygroscopic coefficients of the profile are also shown in the same figure.

Under sweet clover and red clover there was no significant moisture change below the sixth foot throughout the 5-year period. In the sixth foot there was some depletion by sweet clover and slight restoration under red clover.[7] In contrast, alfalfa by the end of the third year had drawn heavily on the subsoil water to the full depth of sampling, and by the end of the fourth and fifth years had reduced it close to the minimum point of exhaustion, as shown in the adjacent 11-year-old field.

UTILIZATION OF MOISTURE FOLLOWING FALLOW

The data on the utilization of moisture following 1 and 2 years of fallow are of interest from two standpoints. One is the rapidity with

[7] The subsoil moisture data for sweet clover are slightly but consistently lower on the average than those for red clover or for alfalfa at the first two dates of sampling. This is viewed as a plat variation inherent in the initial moisture conditions.

TABLE 7.—*The comparative effects of alfalfa, sweet clover, and red clover upon the moisture content of land that had not been previously cropped to alfalfa.*

Depth of soil, feet	Soil moisture content, per cent															
	Initial 1927 fall	After cropping to														
		Alfalfa					Sweet clover					Red clover				
		1929 spring	1929 fall	1930 fall	1931 fall	1932 fall	1929 spring	1929 fall	1930 fall	1931 fall	1932 fall	1929 spring	1929 fall	1930 fall	1931 fall	1932 fall
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
1	16.7	29.5	21.9	15.9	14.6	26.1	29.7	20.7	11.4	19.6	22.0	29.5	20.2	13.7	16.2	26.1
2	17.2	25.4	20.7	16.5	16.1	22.6	27.1	23.1	16.8	19.6	18.9	27.3	21.7	17.5	17.5	18.2
3	15.3	23.9	15.9	15.2	14.8	17.0	24.3	19.3	15.9	15.2	16.4	24.5	16.6	15.8	16.7	16.1
4	14.9	20.8	14.9	15.5	13.9	17.1	21.2	17.6	14.3	16.3	14.8	26.1	16.7	15.1	15.6	16.5
5	17.0	17.5	15.3	14.9	13.4	15.9	18.7	16.5	16.0	16.0	15.4	22.0	17.9	16.0	19.6	18.2
6	19.4	19.7	17.0	14.3	14.5	15.6	18.1	17.2	18.0	18.0	18.7	20.1	19.8	19.9	20.2	20.8
7	21.0	21.4	19.0	14.8	13.2	15.9	20.4	18.9	20.1	19.2	21.5	21.7	20.9	22.4	21.2	20.8
8	21.5	22.0	21.4	15.2	13.6	15.3	20.8	20.0	20.3	19.8	21.6	21.9	21.7	22.3	21.7	21.0
9	22.7	23.9	22.2	15.0	13.6	15.3	22.4	20.8	21.2	20.0	21.8	22.8	23.3	22.1	22.7	22.0
10	22.0	23.0	21.8	14.4	13.0	14.5	22.4	21.2	20.2	20.2	21.2	23.2	23.3	22.3	23.0	21.1
11	22.5	23.3	22.7	14.7	12.8	13.7	22.8	20.9	20.5	20.2	21.5	23.3	22.9	22.6	22.6	22.2
12	23.0	23.5	22.5	15.4	13.1	13.4	22.2	21.2	21.3	20.4	21.4	23.8	23.4	22.6	22.8	22.5
13	23.2	24.1	23.1	16.7	12.8	13.3	22.6	21.3	21.9	20.8	22.0	23.7	23.8	24.2	21.2	22.8
14	21.6	22.1	20.7	16.0	12.4	12.6	21.7	21.3	19.5	19.8	20.7	22.8	21.5	23.4	21.9	22.5
15	20.3	19.7	18.3	15.9	11.8	11.8	19.9	19.0	17.9	17.6	16.2	19.7	18.9	22.1	20.0	20.9
Averages of Successive 5-foot Depths																
1–5	16.2	23.4	17.7	15.6	14.6	19.7	24.2	19.4	14.9	17.3	17.5	25.9	18.6	15.6	17.1	19.0
6–10	21.3	22.0	20.3	14.7	13.6	15.3	20.8	19.6	20.0	19.4	21.0	21.9	21.8	21.8	21.8	21.1
11–15	22.1	22.5	21.5	15.7	12.6	13.0	21.8	20.7	20.2	19.8	20.4	22.7	22.1	23.0	21.7	22.2

which the moisture restored by summer fallow is removed by subsequent cropping to alfalfa and the other is a comparison of the three legumes under the intermediate conditions of the two extremes discussed above. The data are reported in Tables 8 and 9. The second and third columns of each table report the moisture percentages at the beginning and end of the fallow periods. Their differences represent the accumulated water that was subject to depletion by the legumes which followed.

In the plats which had been fallowed for 1 year (Table 8) moisture had accumulated abundantly in the upper 5 feet and slightly in the sixth foot. By the close of the second crop season in 1930 the three legumes had completely exhausted all of this moisture. Subsequent changes were insignificant.

In the plats which had been fallowed for 2 years (Table 9) abundant moisture accumulation was evidenced throughout a depth of 7 feet. By the close of the first season of cropping extensive depletion had occurred to depths of only 4 or 5 feet. Below the fifth foot the moisture content had increased and the moisture front had extended about a foot beyond its initial position, practically the same as in the summer fallow plat of that year (Table 3, Fig. 1). By the close

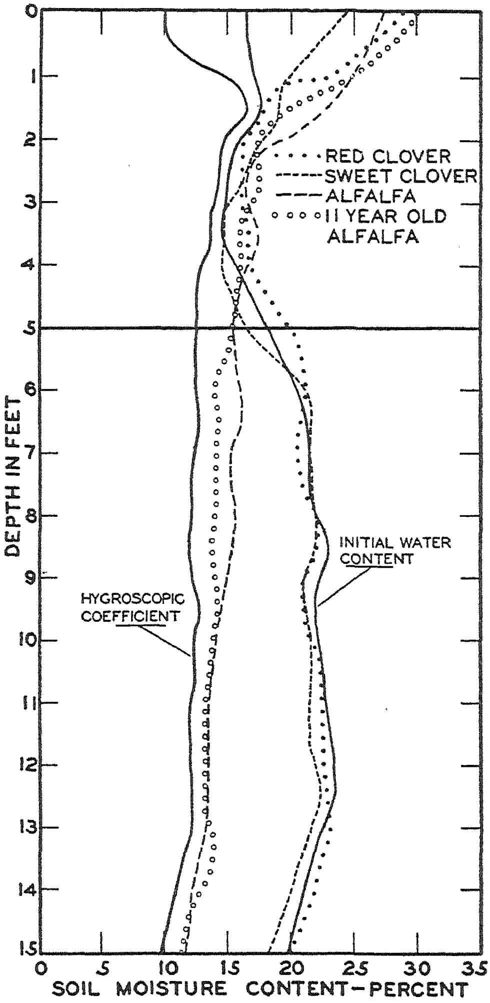

FIG. 2.—Utilization of subsoil moisture during 5 years (1928–1932) by alfalfa, sweet clover, and red clover on land formerly in brome grass (1922–1927) and comparative utilization by 11 years of continuous alfalfa (1922–1932) on adjacent land. The broken and dotted lines give the moisture conditions at the end of the periods (fall, 1932). The solid line on the right indicates the initial water content of the brome grass land in 1927. The solid line on the left indicates the hygroscopic coefficient of the profile.

TABLE 8.—*The comparative effects of alfalfa, sweet clover, and red clover upon the moisture content of soil that had been previously cropped to alfalfa during 6 years, 1922–27, and summer fallowed in 1928.*

Depth of soil, feet	Soil moisture content, per cent										
	Initial 1927 fall	After fallow 1929 spring	After cropping to								
			Alfalfa			Sweet clover			Red clover		
			1930 fall	1931 fall	1932 fall	1930 fall	1931 fall	1932 fall	1930 fall	1931 fall	1932 fall
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	15.3	26.5	11.2	13.6	18.9	11.1	20.2	21.1	11.2	13.0	21.9
2	17.9	27.0	16.5	16.0	18.8	17.3	16.8	17.0	16.0	15.2	19.1
3	16.5	24.8	15.4	14.6	16.3	16.1	14.2	15.6	15.4	14.6	17.1
4	15.5	24.0	13.7	13.8	14.8	15.1	14.0	14.4	15.7	14.6	16.0
5	14.2	19.6	13.4	13.7	14.0	15.3	13.1	14.2	15.4	15.9	16.1
6	14.7	15.5	13.4	13.0	13.5	14.6	13.6	14.3	14.7	14.4	16.2
7	14.9	14.8	13.9	13.2	13.3	14.7	13.3	13.8	14.3	14.3	15.4
8	14.6	15.0	13.8	13.5	13.4	14.6	13.3	14.0	14.5	13.5	15.1
9	14.7	14.8	14.1	14.0	13.8	14.6	13.5	14.4	14.3	13.7	14.8
10	14.3	14.7	14.7	13.4	14.0	15.0	13.5	14.3	15.0	13.3	14.9
11	13.8	14.6	13.8	13.4	13.1	14.5	12.8	13.5	14.3	13.0	14.0
12	13.9	14.0	13.5	13.0	13.0	14.0	12.4	13.4	13.6	13.0	14.1
13	14.0	14.0	13.8	13.4	12.8	13.9	12.4	13.5	14.2	12.6	13.8
14	13.9	14.5	13.8	13.0	13.0	13.6	12.4	13.4	13.9	12.8	14.0
15	12.9	13.9	13.9	12.8	13.0	13.7	12.6	13.1	13.7	13.0	13.7
	Averages of Successive 5-foot Depths										
1–5	15.9	24.4	14.0	14.3	16.6	15.0	15.7	16.5	14.7	14.7	18.0
6–10	14.6	15.0	14.0	13.4	13.6	14.7	13.4	14.2	14.6	13.8	15.3
11–15	13.7	14.2	13.8	13.1	13.0	13.9	12.5	13.4	13.9	12.9	13.9

of the second season, 1931, the storage below the fifth foot was largely and by the following year entirely exhausted by alfalfa. It is evident, therefore, that such fallow practices would have value only insofar as they insure the securing of stands.

Sweet clover and red clover drew upon the stored water during the second season to the full depth of storage, about 8 feet, but not nearly so extensively as alfalfa. The year following, the average soil moisture below the fifth foot under sweet clover showed no definite change. Under red clover, the average had significantly increased. This was doubtless due to the fact that the red clover was reseeded in the spring because of winterkilling, and as a consequence, made insufficient growth to utilize all the water in its root zone. Since considerable fallow-accumulated moisture still remained in the soil, a decided movement downward occurred during 1932.

It is to be observed that sweet clover and red clover both utilized subsoil moisture to a somewhat greater depth when grown on 2-year fallow land than when grown on non-alfalfa ground. This may be due to the unusually favorable moisture and other growth conditions that prevailed in the fallowed soil when the legumes were planted. It is to be noted that the degree of depletion between the fifth and eighth feet, even under these most favorable conditions, was not so extensive that it would interfere with subsequent alfalfa root de-

TABLE 9.—*The comparative effects of alfalfa, sweet clover, and red clover upon the moisture content of soil that had been previously cropped to alfalfa during 6 years, 1922–27, and summer fallowed in 1928 and 1929.*

Depth of soil, feet	Soil moisture content, per cent										
	Initial 1927 fall	After fallow 1929 fall	After cropping to								
			Alfalfa			Sweet clover			Red clover		
			1930 fall	1931 fall	1932 fall	1930 fall	1931 fall	1932 fall	1930 fall	1931 fall	1932 fall
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	15.3	25.2	11.2	18.1	16.7	12.3	11.3	21.9	11.9	12.4	25.8
2	17.9	25.2	17.8	18.7	17.2	17.7	20.4	20.0	16.4	16.4	24.9
3	16.5	24.6	16.9	16.6	15.8	16.4	18.3	16.5	16.6	15.3	19.9
4	15.5	24.3	16.6	15.6	14.1	16.1	18.8	15.2	17.5	18.4	18.1
5	14.2	24.6	19.5	15.9	13.9	17.8	18.9	14.9	23.2	20.5	19.0
6	14.7	24.3	23.9	17.0	13.5	23.3	20.7	16.2	25.4	21.3	21.8
7	14.9	21.6	24.1	16.6	13.4	25.3	19.7	18.3	24.6	19.8	22.8
8	14.6	17.3	22.1	16.0	13.6	23.2	17.1	18.9	20.7	17.8	21.7
9	14.7	16.8	17.5	15.1	13.2	18.7	15.3	17.4	15.0	15.6	20.9
10	14.3	15.8	15.4	14.0	13.7	15.4	13.3	15.6	15.2	14.3	18.1
11	13.8	14.3	14.7	13.4	13.5	15.2	13.3	14.3	15.2	13.4	15.5
12	13.9	14.7	14.0	12.6	13.0	14.3	13.2	13.7	14.2	13.2	14.1
13	14.0	13.7	14.2	12.8	13.2	14.5	12.8	13.3	14.5	13.4	14.0
14	13.0	14.1	14.0	12.8	13.1	14.1	12.5	13.2	14.1	12.9	13.9
15	12.9	13.6	13.8	12.8	12.9	14.1	12.6	13.3	14.0	13.0	13.6
Averages of Successive 5-foot Depths											
1–5	15.9	24.8	16.4	17.0	15.5	16.1	17.5	17.7	17.1	16.6	21.5
6–10	14.6	19.2	20.6	15.7	13.5	21.2	17.2	17.3	20.2	17.8	21.1
11–15	13.5	14.1	14.1	12.9	13.1	14.4	12.9	13.6	14.4	13.2	14.2

velopment. Alfalfa can, therefore, apparently be grown following sweet clover and red clover without suffering any of the adverse effects that occur when it succeeds itself.

FORAGE YIELDS OF ALFALFA, SWEET CLOVER, AND RED CLOVER

From the discussion of the preceding section it is clear that both sweet and red clover differ from alfalfa in that they are largely independent of the deep-seated subsoil moisture supply and make their growth on seasonal rainfall supplemented by the moisture in the upper 6 to 7 feet of soil at seeding time. When the three legumes are grown concurrently on land previously occupied by alfalfa, the clovers would seem to be at no great disadvantage, but the alfalfa would be adversely affected. On the other hand, where there is a plentiful supply of moisture in the lower subsoil, alfalfa will have the advantage. The choice of legume to grow becomes, therefore, a question of relative productivity under the particular moisture conditions that may obtain, when factors of seed and labor cost, forage and pasture quality, and soil improvement are all taken into consideration.

In this section of the paper the yields of the three legumes are reported. The data were obtained for land previously in alfalfa, land never in alfalfa, and alfalfa land fallowed for 1 and 2 years.

ALFALFA COMPARED WITH CLOVERS

Table 10 reports the annual yields of the three legumes as harvested for forage. In interpreting the yields it should be kept in mind that in practice the clovers are commonly grown with grain crops intervening rather than continuously as in these comparisons. Under such conditions the crop of the first year would have a certain value for pasturage and soil improvement. The clover yields reported herewith are for second year growth resulting from August plantings, except for the initial seeding when they were spring planted. These results indicate the yield possibilities of second year clover in comparison with alfalfa grown under the same seasonal and soil moisture conditions.

TABLE 10.—*Comparative annual yields of alfalfa, sweet clover, and red clover on land previously cropped to alfalfa, on alfalfa land summer fallowed for 1 and 2 years, and on land never cropped to alfalfa.*

Previous cropping history	Yield of hay in tons per acre (15% moisture basis)			
	Alfalfa		Sweet clover	Red clover*
	First two cuttings	Total		
1929				
Alfalfa	2.29	2.52	2.23	3.39
Non-alfalfa	2.44	3.15	2.28	3.77
1930				
Alfalfa	1.97	3.28	2.19	2.86
Alfalfa followed by 1 year fallow	2.25	3.05	2.57	3.31
Non-alfalfa	3.27	5.11	2.33	3.20
1931				
Alfalfa	1.76	2.20	3.54	2.65
Alfalfa followed by 1 year fallow	1.86	2.33	3.48	2.53
Alfalfa followed by 2 years fallow	2.40	3.00	3.10	3.16
Non-alfalfa	2.66	3.34	3.64	3.21
1932				
Alfalfa	2.85	3.46	2.93	—
Alfalfa followed by 1 year fallow	3.99	4.60	2.99	—
Alfalfa followed by 2 years fallow	3.79	4.60	2.42	—
Non-alfalfa	4.03	5.17	3.18	—

*Due to winterkilling, no yields are available for 1932.

The relative yields of the three legumes as calculated from their average yields when grown under the various conditions may be summarized as follows, using alfalfa as a basis:

	Alfalfa	Sweet clover	Red clover
On alfalfa sod, 4 years........	100	95	111
On 1-year fallow, 3 years......	100	91	109
On 2-year fallow, 2 years......	100	73	105
On non-alfalfa land, 4 years....	100	68	88

Similarly, the yields from the four different sets of soil conditions may be summarized by using those on alfalfa sod as a basis in each instance:

	Alfalfa	Sweet clover	Red clover
On alfalfa sod, 4 years........	100	100	100
On 1-year fallow, 3 years......	112	104	106
On 2-year fallow, 2 years......	134	85	119
On non-alfalfa land, 4 years....	146	105	114

It appears from these data that red clover[8] is, on the average, somewhat superior and sweet clover inferior in yielding capacity to alfalfa when grown on land depleted of subsoil moisture. When a plentiful supply of subsoil moisture is available, however, alfalfa is capable of producing considerably higher yields.

COMPARATIVE ALFALFA YIELDS UNDER VARIOUS CONDITIONS

The question frequently arises in connection with fields of alfalfa in which the subsoil moisture has become so depleted that production is dependent entirely on rainfall as to which is the most profitable practice to follow; whether to continue the field as long as a satisfactory stand persists, to plow it up and reseed, or to summer fallow for a year or longer with the idea of restoring subsoil moisture prior to replanting. The alfalfa yield data have been summarized in Table 11 to show the annual and total tonnage accruing from the various systems under study during the 5-year period, 1928 to 1932, and the average annual yields during comparable years. Included in the table are data from a field being cropped to alfalfa for the first time.

Of the fields on the land which was first seeded to alfalfa in 1922. the highest total tonnage per acre was obtained from the continuous alfalfa and the second highest from that reseeded immediately on alfalfa sod. Although the difference is not significant, the former would appear the more profitable for its only costs were those of harvesting. The higher tonnage from continuous alfalfa was due to its yield in 1928, whereas there was no hay to be harvested from the meadow which was reseeded in the spring of that year. During the four subsequent years it averaged only 83% of the reestablished alfalfa.

Fallowing for 1 year as compared with reseeding immediately increased the average annual yield during corresponding years by 0.35 ton per acre. The total tonnage, however, was reduced by 1.48 tons which obviously rendered it unprofitable when costs are taken into consideration. Similarly, 2 years of fallow increased the average yield 0.97 ton per acre during comparable years but resulted in a re-

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[8] The red clover comparisons are for 1 year less in each instance than for the other two legumes.

TABLE 11.—*Yields and total tonnage of alfalfa during the period 1928–32 under the conditions of continued cropping following 6 years of previous alfalfa, when reseeded immediately following alfalfa and after 1 and 2 years of summer fallow, and from land not previously cropped to alfalfa.*

Year	Yield of hay in tons per acre (15% moisture basis)				
	Alfalfa land initially seeded 1922				Non-alfalfa land seeded 1928
	Con-tinuous*	Reseeded			
		1928 without fallow	1929 after 1 year fallow	1930 after 2 years fallow	
1928.........	2.11	—	—	—	—
1929.........	2.39	2.52	—	—	3.15
1930.........	2.20	3.28	3.05	—	5.11
1931.........	1.77	2.20	2.33	3.00	3.34
1932.........	3.13	3.46	4.60	4.60	5.17
Total......	11.60	11.46	9.98	7.60	16.77
Av. 1929–32	2.37	2.87	—	—	4.19
Av. 1930–32	2.37	2.98	3.33	—	4.54
Av. 1931–32	2.45	2.83	3.47	3.80	4.26

*As a 4-year average, 1923–26, this meadow yielded 4.63 tons per acre.

duction of 3.86 tons in total yield. It is evident, therefore, that fallowing under the climatic and soil conditions of eastern Nebraska can not prove an economic practice in alfalfa production.

The outstanding annual yields and total tonnage were obtained from alfalfa seeded on non-alfalfa ground. Total tonnage per acre for the period was 5.17 tons higher than from continuous alfalfa, 5.31 tons higher than from reseeded alfalfa, 6.79 tons higher than from 1-year fallow land, and 9.17 tons higher than from 2-year fallow land. Obviously, the most profitable procedure, once a field of alfalfa under eastern Nebraska upland soil conditions has become depleted of subsoil moisture, is to plow up the crop and reseed on other land that has never grown alfalfa. The next most profitable procedure, if alfalfa is the preferred legume, is to allow the field to continue as long as a satisfactory stand remains and then to plow it up and reseed, either immediately if conditions are favorable, or later if an interval of cropping is preferred. Deliberate effort toward subsoil moisture restoration is likely to be a very disappointing procedure except under most advantageous circumstances.

SUMMARY

These investigations concerning subsoil moisture relations and the production of alfalfa, sweet clover, and red clover were conducted on adjacent areas which differed only with respect to previous cropping.

Following the crop season of 1927, the field that had been cropped to alfalfa during the preceding 6 years contained an average of 14.7% moisture to a depth of 15 feet compared with 19.9% for the non-alfalfa land which had been in brome grass during the same period. This represents 2.2 and 7.4% moisture in excess of the hygroscopic coefficient in the respective areas.

Subsequent to 6 years cropping to alfalfa, 1.25, 6.37, and 21.42 inches of water were restored to the upper 15 feet of soil as a result of 5 years cropping to a 3-year grain rotation, to continuous corn, and to summer fallow, respectively. The moisture stored from the 6- to 15-foot levels under the respective treatments was equivalent to 0.13, 3.12, and 13.17 inches, or 0.1, 2.4, and 10.3% of the total rainfall. As a result of 1, 2, 3, 4, and 5 years of summer fallow the soil reached its approximate field carrying capacity through the fourth, seventh, eighth, ninth, and eleventh foot, respectively.

There was no material change in subsoil moisture following 5 years of cropping to alfalfa, sweet clover, and red clover on land that had been depleted of its available subsoil moisture due to a previous cropping to alfalfa.

On land not previously cropped to alfalfa and holding a relatively high amount of available subsoil moisture, there was no material change in the soil moisture below the sixth foot following 5 years cropping to sweet clover and red clover. When cropped to alfalfa, however, the subsoil moisture had been reduced close to the minimum point of exhaustion to the full depth of sampling (15 feet) by the end of the fourth year.

On the land that had been depleted of its subsoil moisture to great depths by 6 years cropping to alfalfa, the relative yields during a 4-year period of subsequent cropping to alfalfa, sweet clover, and red clover were 100, 95, and 111%, respectively. Correspondingly, on land that had not previously been in alfalfa, the relative yields were 100, 68, and 88. It is thus apparent that alfalfa is superior in yield to the clovers on upland growing this crop for the first time, but it may be equalled or surpassed in tonnage by sweet clover or red clover where the subsoil moisture has been depleted. Economic considerations other than yield, however, may determine which of these three legumes is most desirable on land that has previously been cropped to alfalfa.

The average annual alfalfa yield was 4.19 tons per acre during 4 years on land not previously cropped to alfalfa, compared with 2.37 tons for a comparable old alfalfa meadow and 2.87 tons for a new stand on old alfalfa sod. Since the alfalfa made insufficient growth to be harvested for hay the first year after seeding in the spring, this loss of crop should be charged against the newly sown alfalfa. This gives 5-year total yields of 16.76, 11.60, and 11.46 tons per acre for the land not previously cropped to alfalfa, for the land continued in alfalfa, and for that resown to alfalfa, respectively.

Compared with 3.33 tons per acre as a 3-year average following 1 year of fallow on alfalfa sod, the yield was 4.54 tons on land not previously cropped to alfalfa and 2.98 tons per acre for alfalfa resown on alfalfa land. A total yield of 9.98 tons per acre was harvested from the land fallowed 1 year prior to reseeding.

Two years of fallow on alfalfa sod before seeding increased the 2-year average yield of alfalfa to 3.80 tons compared with 3.47 tons after 1 year of fallow, 2.83 tons with no fallow, and 4.26 tons on land in alfalfa for the first time. The total yield from the 2-year fallow land was 7.60 tons per acre.

SOME CHEMICAL AND BIOLOGICAL EFFECTS OF CYANAMID AND CERTAIN OTHER NITROGENOUS FERTILIZERS ON VARIOUS IOWA SOILS[1]

MARK H. BROWN[2]

Cyanimid was one of the first nitrogenous fertilizers to be prepared synthetically and has now become an important fertilizer commercially. A large number of investigators, both in Europe and America, have studied its chemical effects on soils and on the growth and action of soil micro-organisms. The results which have been reported vary considerably but indicate that cyanamid tends to decrease soil acidity, increases water-soluble phosphorus, and has a marked effect on the soil flora, particularly a depressing effect on nitrification. The purpose of the work reported here was to study the effects of cyanamid and certain other nitrogenous fertilizers on various chemical and biological activities in some Iowa soils.

EXPERIMENTAL

The first experiment was set up in the greenhouse to test the effect of cyanamid, Ammo Phos, sodium nitrate, ammonium sulfate, and superphosphate on certain micro-organic activities, on the soil reaction, and on the amount of soluble phosphorus present in Carrington loam containing 4,300 pounds of nitrogen and 3,600 pounds of phosphorus per acre. Four-gallon glazed pots were filled with screened virgin soil secured from the Agronomy farm of the Iowa Agricultural Experiment Station. Fertilizer applications were thoroughly mixed with the soil in duplicate pots on the basis of the amount of nitrogen contained in 100 and 300 pounds of cyanamid and the amount of phosphorus contained in 191 and 573 pounds of Ammo Phos, as shown in Table 1.

The moisture content was adjusted to approximately 50% of the saturation capacity and was maintained at that point during the experiment by additions of distilled water.

The soils were sampled at 2-week intervals. At one sampling studies were made of the ammonifying power, the nitrogen-fixing power, the amounts of soluble phosphorus, and the numbers of molds and bacteria present. At the next sampling studies were made on the soil reaction, the nitrite and nitrate accumulation, and the nitrifying power of the soils.

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[1] Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Part of a thesis submitted in partial fulfillment of the requirements for the degree doctor of philosophy, Iowa State College. Received for publication July 31, 1933.

[2] Assistant in Soils. The author wishes to express appreciation to the American Cyanamid Company which made this work possible, to Dr. P. E. Brown for aid in outlining the problem and in preparing the manuscript, and to Dr. F. B. Smith for guidance and aid in the laboratory work.

TABLE 1.—*Fertilizer applications and amount of plant food supplied.*

Pot No.	Fertilizer		Available plant food supplied	
	Treatment	Pounds per acre	N %	P_2O_5 %
1, 2....	Check (no treatment) ..	—	—	—
3, 4....	Cyanamid............	100	21.00	—
5, 6....	Cyanamid............	300	21.00	—
7, 8....	Ammo Phos...........	191	11.00	47.0
9, 10...	Ammo Phos...........	573	11.00	47.0
11, 12...	Sodium nitrate........	129	16.25	—
13, 14...	Sodium nitrate........	387	16.25	—
15, 16...	Ammonium sulfate.....	101	20.75	—
17, 18...	Ammonium sulfate.....	303	20.75	—
19, 20...	Superphosphate.......	449	—	20.0
21, 22...	Superphosphate.......	1,346	—	20.0

THE EFFECT OF THE FERTILIZERS ON SOIL REACTION

The reaction or pH of the various soils was determined each month by the use of the quinhydrone electrode. The average results for the duplicate soils are recorded in Table 2.

TABLE 2.—*The effect of certain fertilizers on soil reaction.*

Treatment	Pounds per acre	pH on date of sampling			
		Dec. 16	Jan. 17	Feb. 18	Mar. 19
None..................	—	6.10	6.02	5.90	5.98
Cyanamid.............	100	6.17	6.07	6.02	6.08
Cyanamid.............	300	6.20	5.05	5.97	6.06
Ammo Phos A..........	191	6.10	5.92	5.87	5.89
Ammo Phos A..........	573	5.78	5.74	5.73	5.86
Sodium nitrate..........	129	6.21	6.10	6.04	6.16
Sodium nitrate..........	387	6.25	6.08	6.09	6.13
Ammonium sulfate.......	101	6.24	6.05	6.06	6.07
Ammonium sulfate.......	303	5.94	5.82	5.90	5.85
Superphosphate.........	449	6.29	6.08	6.10	6.12
Superphosphate.........	1,346	6.07	5.85	5.93	5.88

A study of the results in the table shows that there was a gradual decrease in the pH of all the soils for 2 months and this was followed by a slight increase during the third month. The soils receiving the larger applications of Ammo Phos and ammonium sulfate were low in pH throughout the experiment. Applications of sodium nitrate and cyanamid increased the pH above that of the untreated soil and maintained this position throughout the 3 months.

THE EFFECT OF THE FERTILIZERS ON SOLUBLE PHOSPHORUS

The term soluble phosphorus has been applied to the phosphorus which is extracted by the method of Truog (11).[3] The average results are recorded in Table 3.

A study of the table shows that the amounts of phosphorus extracted by this method were very small, but the figures reported

[3] Numbers in parenthesis refer to "Literature Cited," p. 450.

TABLE 3.—*The effect of certain fertilizers on the phosphorus in soil.*

Treatment	Pounds per acre	Dates of sampling				
		Nov. 29	Dec. 31	Feb. 3	Mar. 5	Apr. 2
No treatment.......	—	0.21*	0.26	0.22	0.20	0.33
Cyanamid..........	100	0.23	0.22	0.24	0.38	0.39
Cyanamid..........	300	0.26	0.24	0.23	0.22	0.40
Ammo Phos A......	191	0.44	0.41	0.46	0.54	0.65
Ammo Phos A......	573	0.92	0.84	0.80	0.83	1.35
Sodium nitrate......	129	0.24	0.21	0.24	0.26	0.23
Sodium nitrate......	387	0.22	0.20	0.21	0.21	0.23
Ammonium sulfate..	101	0.23	0.20	0.22	0.33	0.24
Ammonium sulfate..	303	0.26	0.27	0.26	0.24	0.28
Superphosphate.....	449	0.64	0.67	0.52	0.50	0.56
Superphosphate.....	1,346	1.34	1.18	1.00	0.95	0.77

*P.p.m. of phosphorus soluble in 0.002 N sulfuric acid.

are quite consistent from month to month for the different treatments.

Applications of cyanamid caused a marked increase in the soluble phosphorus in these soils. With the Ammo Phos treatments there was an increase from month to month, while with superphosphate the amounts decreased from month to month. In the sodium nitrate and ammonium sulfate treated soils, the amount of soluble phosphorus remained practically the same throughout the experiment.

THE EFFECT OF THE FERTILIZERS ON NITRATE ACCUMULATION

The total nitrate content of the soils was determined by the phenoldisulfonic acid method as modified by Harper (4). The average results are recorded in Table 4.

TABLE 4.—*The effect of certain fertilizers on nitrate accumulation in soil.*

Treatment	Pounds per acre	Date of sampling			
		Jan. 17	Feb. 18	Mar. 19	April 18
No treatment.......	—	2.22*	2.70	3.36	4.60
Cyanamid..........	100	2.43	2.83	3.47	5.02
Cyanamid..........	300	3.72	4.01	4.52	6.90
Ammo Phos A.......	191	2.60	2.83	3.62	5.26
Ammo Phos A.......	573	4.52	5.02	5.25	7.43
Sodium nitrate......	129	3.20	3.20	3.96	5.82
Sodium nitrate......	387	4.00	4.82	5.41	8.45
Ammonium sulfate...	101	2.44	2.81	3.87	5.71
Ammonium sulfate...	303	5.12	5.72	6.19	8.52
Superphosphate.....	449	2.52	2.90	3.57	5.28
Superphosphate.....	1,346	3.00	3.52	3.71	5.66

*Mgm nitrate nitrogen per 100 grams air-dry soil.

These results show an increase in the nitrate content of all the soils from the first to the last sampling. The soils treated with sodium nitrate showed the highest nitrate content at all samplings, and those treated with ammonium sulfate increased at the various samplings until their content at the end practically equalled that in the soils treated with sodium nitrate. Both applications of superphosphate caused substantial increases in nitrates. The amount of nitrates in the soils treated with Ammo Phos showed no indication that the phosphate present in this material had any effect on nitrate accumulation in the soil. The soils treated with cyanamid showed the smallest accumulation of nitrates of any of the treated soils.

THE EFFECT OF THE FERTILIZERS ON NITRITE ACCUMULATION

The nitrite content of the soils was determined according to the method outlined by Fraps (1). This determination was made as soon after sampling as possible as it was found that any nitrites present disappeared within an hour or two. Nitrites were never found in appreciable amounts and after the third determination no further tests were made.

THE EFFECT OF THE FERTILIZERS ON NUMBERS OF MOLDS AND BACTERIA

The numbers of molds and bacteria were determined by making the usual infusions and dilutions and plating within 12 hours after sampling.

Fifty grams of moist soil and 500 cc of 0.87% sodium chloride solution were used in making the infusions. Peptone-glucose acid agar was used as the medium for molds and sodium albuminate agar for bacteria (2). The counts were made after incubation of the plates at room temperature for 3 and 7 days for the molds and bacteria, respectively. The average results of the mold counts are given in Table 5 and of the bacterial counts in Table 6.

TABLE 5.—*The effect of certain fertilizers on numbers of molds in soil.*

Treatment	Pounds per acre	Dates of sampling				
		Nov. 29	Dec. 31	Feb. 3	Mar. 5	Apr. 2
No treatment.......	—	20,500*	4,000	10,000	2,000	9,000
Cyanamid..........	100	24,500	8,000	13,000	3,000	10,000
Cyanamid..........	300	18,000	4,500	10,000	4,000	9,000
Ammo Phos A......	191	21,500	6,000	11,500	4,000	10,000
Ammo Phos A......	573	26,500	7,000	13,500	3,000	9,500
Sodium nitrate......	129	22,500	4,000	14,000	4,000	12,000
Sodium nitrate......	387	27,000	2,500	12,000	3,500	12,000
Ammonium sulfate..	101	22,000	4,500	9,000	2,000	7,500
Ammonium sulfate..	303	30,000	3,000	8,500	4,500	10,000
Superphosphate.....	449	34,500	7,000	13,000	7,500	13,500
Superphosphate.....	1,346	48,000	11,500	17,000	9,000	16,500

*Numbers per gram of moist soil.

The numbers of molds showed a sharp decrease during the first month and thereafter quite definite increases and decreases from month to month. With the exception of superphosphate, none of

TABLE 6.—*The effect of certain fertilizers on numbers of bacteria in soil.*

Treatment	Pounds per acre	Dates of sampling				
		Nov. 29	Dec. 31	Feb. 3	Mar. 5	Apr. 2
No treatment	—	1,950*	900	800	405	485
Cyanamid	100	1,800	1,050	600	455	455
Cyanamid	300	1,500	1,500	1,200	495	500
Ammo Phos A	191	1,800	1,000	450	489	510
Ammo Phos A	573	2,100	1,200	800	565	585
Sodium nitrate	129	1,950	650	500	450	580
Sodium nitrate	387	2,600	600	300	505	500
Ammonium sulfate	101	2,200	850	500	455	535
Ammonium sulfate	303	2,150	850	400	480	430
Superphosphate	449	1,900	1,200	700	630	730
Superphosphate	1,346	1,950	1,000	1,600	825	720

*Thousands of bacteria per gram of moist soil.

the fertilizer treatments had any great effect. The results on the superphosphate-treated soils show that this material had a marked stimulating effect.

The numbers of bacteria also showed the same tendency to decrease as was noted in the case of the molds. The decrease in the case of the bacteria continued until the sampling on March 5 and was then followed by a slight increase in many of the soils. As in the case of the molds, the superphosphate treatments brought about a small, but definite, increase in numbers. The cyanamid-treated soils showed a slower decrease during the first 2 months than did the other nitrogen-treated soils.

THE EFFECT OF THE FERTILIZERS ON THE AMMONIFYING POWER OF SOILS

The ammonifying power of the soils was measured by determining the amount of ammonia produced in 100 grams of soil treated with 5 grams of dried blood. The moisture content was adjusted to the optimum and the samples incubated for 7 days at room temperature. The ammonia was determined by the aeration method described by Potter and Snyder (10).

The average results reported in Table 7 show that the ammonifying power of the soils increased slowly up to March 5 and then decreased sharply. While the superphosphate-treated soils showed some increase in ammonifying power, none of the other treated soils showed any great effects from the treatments, only a slight increase over the untreated soil appearing.

THE EFFECT OF THE FERTILIZERS ON THE NITRIFYING POWER OF THE SOILS

The nitrifying power of the soils was measured by determining the amount of nitrates produced in 100 grams of soil treated with 30 mgm of nitrogen as ammonium sulfate. The moisture content of the soil was maintained at optimum and the samples incubated for 4 weeks at room temperature. The average results are given in Table 8. The figures given represent the differences between

TABLE 7.—*The effect of certain fertilizers on the ammonifying power of soil.*

Treatment	Pounds per acre	Dates of sampling				
		Nov. 29	Dec. 31	Feb. 3	Mar. 5	Apr. 2
No treatment.......	—	110*	131	126	130	70
Cyanamid..........	100	120	123	140	142	82
Cyanamid..........	300	98	122	135	143	86
Ammo Phos A......	191	124	126	150	161	88
Ammo Phos A......	573	102	147	157	160	94
Sodium nitrate......	129	102	125	140	147	90
Sodium nitrate......	387	104	124	128	147	89
Ammonium sulfate..	101	130	117	127	143	83
Ammonium sulfate..	303	112	117	131	156	90
Superphosphate.....	449	95	136	140	155	89
Superphosphate.....	1,346	120	136	130	157	88

*Mgm ammonia produced per 100 grams of air-dry soil.

the nitrate content of the soils at the beginning and at the end of the incubation period, with the following exception. As the results of the nitrate determinations on the soils sampled on December 16 were lost, the amount of nitrates present in the soils on January 17 were used in making the calculations for the figures reported for December 16.

TABLE 8.—*The effect of certain fertilizers on the nitrifying power of soil.*

Treatment	Pounds per acre	Date of sampling				
		Dec. 16	Jan. 17	Feb. 18	Mar. 19	Apr. 18
No treatment.......	—	6.20*	8.99	5.59	4.94	5.38
Cyanamid..........	100	5.73	8.67	5.34	4.70	4.82
Cyanamid..........	300	5.80	8.12	6.14	5.63	5.62
Ammo Phos A......	191	5.49	8.39	5.50	4.72	4.33
Ammo Phos A......	573	6.00	8.78	4.59	4.39	4.60
Sodium nitrate......	129	6.18	9.61	6.62	5.84	4.64
Sodium nitrate......	387	5.36	9.66	6.11	5.53	4.38
Ammonium sulfate..	101	6.73	10.30	6.86	5.30	5.78
Ammonium sulfate..	303	6.96	11.83	5.92	5.50	4.89
Superphosphate.....	449	8.20	11.87	7.05	6.38	6.97
Superphosphate.....	1,346	6.43	9.27	5.89	5.70	6.06

*Mgm nitrate nitrogen produced per 100 grams air-dry soil.

A study of the table shows that the nitrifying power increased in the first month, decreased during the next month, and changed but little through the next 2 months. With the exception of a slight increase from the superphosphate treatments, no marked effects from the various fertilizer additions are evident.

The amounts of nitrites present in the nitrification culture experiments were determined. However, as no appreciable amounts were found, these determinations were not made after the third sampling.

THE EFFECT OF THE FERTILIZERS ON NITROGEN FIXATION

The nitrogen-fixing power of the soils was determined by the use of nitrogen-free mannitol solutions (2), inoculation with 10 cc of a 1 to 10 soil infusion, and incubation for 3 weeks at room temperature.

The nitrogen in the cultures was then reduced with Devarda's alloy and determined by the Kjeldahl-Gunning method. After two determinations showed no nitrogen fixed, no further tests along this line were made.

On January 21, tests were made on all the soils for the presence of Azotobacter by Winogradsky's macroscopic spontaneous culture method. After incubation for 3 days at 26°C, the surface of the soils was well covered with colonies indicating the presence of Azotobacter.

DISCUSSION

The results of the determinations of the effect of the fertilizers tested on the soil reaction show that the addition of ammonium sulfate, superphosphate, and Ammo Phos caused marked decreases in pH, while soils treated with cyanamid and sodium nitrate had the highest pH values throughout the experiment. Cyanamid contains 17.5% calcium hydroxide and it is probable that this material has an immediate effect on soil reaction. The effects noted with this material agree with the results reported by Lipman and Blair (7), Hartwell (5), Fudge (3), Niklas and Hock (8), and Pierre (9).

The study of the effect of the fertilizers on soluble phosphorus shows that the amounts of soluble phosphorus present in these soils were generally small. However, some of the results are quite suggestive. Cyanamid caused a marked increase in the amounts of soluble phosphorus present. These results agree with those reported by Fudge (3) and Jensen (6). The amounts of soluble phosphorus present in the soils treated with ammonium sulfate and sodium nitrate remained constant throughout the experiment. In the soils receiving superphosphate there was a marked decrease during the experiment in the amounts of soluble phosphorus, while the opposite was true of the soils receiving equivalent amounts of phosphorus in the form of Ammo Phos. The decrease in the superphosphate-treated soils may have been due in part to a reversion of a part of the phosphate to the less soluble calcium compounds, although it seems more probable that it was due to assimilation by micro-organisms.

The tests of the effect of the fertilizers on nitrate accumulation showed that no marked differences occurred with the various soils. As was expected, the soils receiving nitrate additions showed the highest nitrate content throughout the experiment. Those receiving ammonium sulfate steadily increased in nitrate content until the amount practically equalled that in the nitrate-treated soils at the last sampling. The effect of a phosphate in stimulating the production of ammonia from the organic matter in the soil was reflected in the nitrate content of the soils receiving superphosphate, but there was no effect from the Ammo Phos. The soils receiving cyanamid showed the lowest nitrate accumulation of any of the treated soils.

No evidence was found that nitrites occurred in appreciable amounts in any of these soils and any nitrites formed disappeared rapidly after sampling.

The results of the study of the effect of the fertilizers on numbers of molds and bacteria indicate a marked decrease in numbers of bacteria and molds during the first month after which an increase occurred. With the exception of the stimulation due to the applications of superphosphate, few important differences were noted between the variously treated soils either in numbers of molds or bacteria. The results do indicate that applications of sodium nitrate may cause slight increases in numbers of molds and that applications of 300 pounds of cyanamid per acre may have a slight depressing effect on numbers of bacteria when first applied, but this was followed by an increase the following month.

The results of the studies of the ammonifying power of the soils showed that only slight increases occurred with applications of fertilizers. Fertilizers containing phosphorus appear to have a slightly greater stimulating effect than the others, although no very significant increases were noted. It appears, however, that bacteria were the important ammonifying organisms in these soils as the marked periodic increases and decreases in numbers of molds were not reflected in the amounts of ammonia produced from dried blood. It should be noted that the amounts of ammonia produced could not have been limited by the amount of material present to be ammonified as 5 grams of dried blood containing about 12% nitrogen would yield about 600 mgm of ammonia if completely decomposed. It is interesting to note that this relation between numbers of bacteria and ammonifying power is similar to that noted in later experiments.

Nitrification results indicate that applications of the fertilizers tested had no appreciable effect on the nitrifying power of the soils, although there is an indication that phosphorus may have had a slight stimulating effect. Nitrites were never found in appreciable amounts in the nitrification cultures.

Although tests made by the Winogradsky method indicated that Azotobacter were present in all the soils, no nitrogen was fixed in solution cultures. It should be borne in mind that, although these organisms may exist at a pH of 5.8, they do not function at a pH below 6.6 to 6.8. It is possible, therefore, that the organisms present were not very vigorous.

SUMMARY

1. Applications of cyanamid and sodium nitrate increased the pH of the soil, while ammonium sulfate and Ammo Phos caused a decrease when these materials were applied in amounts equivalent to 21 and 63 pounds of nitrogen per acre, respectively.

2. Applications of cyanamid caused a marked increase in the amount of soluble phosphorus present in soil, while sodium nitrate and ammonium sulfate applied in equivalent amounts of nitrogen had no effect.

3. Applications of cyanamid, sodium nitrate, ammonium sulfate, and Ammo Phos exerted no marked effect on the nitrate accumulation in the soil, on the number of molds and bacteria present, on the ammonifying power of the soil, or on the nitrifying power of the soil. Applications of superphosphate, however, brought about some increase in biological activity.

4. The number of molds in soil had no marked effect on the amount of ammonia produced from dried blood in ammonification

tests. The amounts produced were not affected by marked changes in numbers of bacteria.

LITERATURE CITED

1. FRAPS, G. S. Availability of some nitrogenous and phosphatic materials. Tex. Agr. Exp. Sta. Bul. 287. 1922.
2. FRED, E. B., and WAKSMAN, S. A. Laboratory Manual of General Microbiology. New York: McGraw-Hill Book Co. 1928.
3. FUDGE, F. J. Influence of various nitrogenous fertilizers on the availability of phosphate and potassium. Ala. Agr. Exp. Sta. Bul. 227. 1928.
4. HARPER, H. J. The accurate determination of nitrates in soils. Jour. Ind. and Eng. Chem., 16 : 180–183. 1924.
5. HARTWELL, B. L. Fortieth Annual Report of the Director of the Agricultural Experiment Station. R. I. Agr. Exp. Sta. Ann. Rpt. 1928.
6. JENSEN, C. A. Solubility of plant food elements as modified by fertilizers. Jour. Amer. Soc. Agron., 8 : 100–105. 1916.
7. LIPMAN, J. G., and BLAIR, A. W. Field experiments on the availability of nitrogenous fertilizers. Soil Science, 26 : 1–21. 1928.
8. NIKLAS, H., and HOCK, A. Beeinflussung des Bodenreaktion durch Kalkstickstoff. Fortschr. Landw., 1 : 557–562. 1926.
9. PIERRE, W. H. Nitrogenous fertilizers and soil acidity: I. Effect of various nitrogenous fertilizers on soil reaction. Jour. Amer. Soc. Agron., 20 : 254–269. 1928.
10. POTTER, R. S., and SNYDER, R. S. The determination of ammonia in soils. Iowa Agr. Exp. Sta. Res. Bul. 17. 1914.
11. TRUOG, E. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22 : 874–882. 1930.

BOOK REVIEW

SUPPRESSION OF WEEDS BY FERTILIZERS AND CHEMICALS

By H. C. Long. Published by the author, Surbiton, Surrey, England. 57 pages, illus. 1934. 2s. 2d. postpaid.

This little booklet, with a foreword by Sir A. D. Hall, presents in a popular manner a review of the extensive literature dealing with the subject. Agronomists interested primarily in weed eradication will find it a useful addition to their libraries.

The following chapter headings indicate clearly the extent of the work: Losses Due to Weed Infestation; Effect of Fertilizers in Reducing Weeds; The Use of Lime; Sulfate of Ammonia and Nitrate of Soda; Calcium Cyanamide; Sulfuric Acid; Sulfates of Copper and Iron; Finely Powdered Kainit; Sodium and Potassium Chlorates; Compounds of Arsenic; and Miscellaneous Materials. The booklet concludes with a list of the 78 weeds discussed in the text. (J. D. L.)

ERRATA

On page 228 of the current volume of the JOURNAL, the value for the difference for significance in column 2 of Table 3 should be 2.28.

Also, on page 253 of the current volume, the first figure in column 3 of Table 1 should be 8,980.

AGRONOMIC AFFAIRS

MEETING OF WESTERN BRANCH OF SOCIETY WITH A. A. A. S.

The Western Branch of the American Society of Agronomy will hold a joint meeting with Section O of the American Association for the Advancement of Science in Berkeley, California, beginning Monday, June 18.

In addition to the section meetings, agriculture will have two general section programs of interest to agronomists: (1) Weed Control, arranged by W. W. Robbins; and (2) Land Utilization, arranged by H. E. Erdman. Over twenty societies are planning to meet at Berkeley. Among those that should have programs of interest to agronomists are the Western Society of Soil Science, Botanical Society of America, American Society of Plant Physiologists, American Phytopathological Society, Ecological Society of America, Western Society of Naturalists, and the Genetics Society of America.

A number of excursions have been arranged: Mt. Tamalpais and Muir Woods, Stanford University, Golden Gate Park, the California Academy of Sciences, San Francisco, Mt. Hamilton, the Lick Observatory, Strawberry Canyon, the Botanical Garden, etc. On Saturday, June 23, there will be an excursion to the University Farm at Davis, where the agronomists will have an opportunity to see the field work of the Agronomy Department of the University of California.

General headquarters and registration offices will be in Stephens Union. The lounging rooms will be kept open during the week as a central social gathering place. Registration will be on Monday, June 18th at 9:00 A. M., fee $1.00. The program will be given out on registration. In the preliminary announcement which will appear in *Science* in May a list of hotel accommodations will be given. D. E. Stephens, Moro, Oregon, is President of the Western Branch of the Society, and F. N. Briggs, Davis, Calif., Secretary.

MEETING OF NORTHEASTERN SECTION

The annual meeting of the Northeastern Section of the Society will be held at the New Jersey Agricultural Experiment Station at New Brunswick, N. J., on June 21 to 23. Details of the program were not available when the Journal went to press. Professor R. P. Thomas, Department of Agronomy, University of Maryland, College Park, Md., is Secretary-Treasurer of the Northeastern Section.

NEWS ITEMS

P. W. WHITE of Pennsylvania State College was selected as the first annual research lecturer by the College Senate Research Committee and on May 11 delivered an address at a public meeting on the campus on "The Scope and Significance of Our Soil Research Program."

G. A. CRABB of the University of Georgia has been granted leave of absence from the University to become Chief Soils Expert with the Soil Erosion Service of the U. S. Dept. of the Interior. Professor Crabb will direct the soils work on the $300,000 erosion control project in the Sandy Creek region of Clarke, Jackson, and Madison counties, Georgia.

A GENETICIST with a Ph.D. from Harvard desires a teaching or research position in plant or animal genetics, plant breeding, agronomy, botany, or zoology. He has had five years experiment station experience in breeding crop plants and teaching experience in genetics. For further information, address the Editor of this JOURNAL.

DR. CLARENCE DORMAN recently resigned as Instructor in Soils and Assistant in the Experiment Station at Michigan State College to accept a position as Professor in Soils and Associate Agronomist in the Experiment Station of the Mississippi State College.

M. M. HOOVER, Associate Professor of Agronomy at West Virginia University, has resigned to become Regional Director of the Soil Erosion Service located at Spencer, W. Va.

C. R. BURNHAM has been appointed Assistant Professor of Genetics and L. S. Bennett, Instructor in Agronomy and Genetics, in the Department of Agronomy and Genetics of West Virginia University.

THATCHER WHEAT is the name given a new variety of hard red spring wheat by the Minnesota Agricultural Experiment Station in honor of Dr. R. W. Thatcher, former Dean of the University Department of Agriculture. The new variety has proved so promising in field, milling, and baking tests that it has replaced Marquillo on the list of recommended varieties of the Minnesota Experiment Station.

JOURNAL

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THE DIRECT PLANTING AND TRANSPLANTING OF RICE IN CHINA[1]

T. H. SHEN[2]

It is the purpose of this paper to set forth results obtained from rice experiments in which the same varieties are compared when grown by the transplanting method which is commonly used by the rice farmers of China and the direct planting method. In the latter method the seed is sown dirctly in the field where the crop is to be grown and was first suggested by H. H. Love in 1925 and adopted for the breeding tests conducted by the Department of Agronomy of the University of Nanking in that year. The method was suggested to save labor and to reduce the chances of error in handling the material.

In the rice belt of China rice is planted after a winter crop such as wheat, barley, rape, or some legumes. Chiefly on account of such rotation, the transplanting of rice can hardly be replaced by direct planting, and the question naturally arises whether the results of the breeding test by direct planting can be applied to the farmer's practice of transplanting.

The writer investigated this question from 1928 to 1932 at Nanking, and at the Chekiang Provincial Experiment Station of Agriculture at Hangchow in 1931, as well as at the substation at Wufu southeast of Hangchow. Nanking is on the border of the rice belt of China and only medium late rice is grown there, while at Hangchow medium late and late varieties prevail and at Wufu early, medium-late, and late varieties. Rainfall and the possibility of irrigation are favorable for rice at Hangchow and Wufu but not so favorable at Nanking. With this difference in environment, the effects upon the methods of planting in the breeding test can be studied.

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[1] Contribution from the Department of Agronomy, University of Nanking, Nanking, China. In addition to data obtained from experiments conducted by the Department of Agronomy, University of Nanking, the author includes certain data from the Chekiang Provincial Experiment Station of Agriculture, Hangchow, which were collected while he was serving there as Head of Agronomy. Received for publication April 22, 1933.

[2] Professor of Plant Breeding. The author desires to express his appreciation to C. I. Swen, C. Chen, H. N. Shen, and C. L. Pan for their assistance in the field work during this investigation and to C. L. Tsou for his help in the identification of the damage caused by the stem borer.

METHOD AND MATERIALS

Native or adapted varieties were used in this study. Each plat consisted of three rows, 14.25 feet long with 1.5 feet between the rows. A check was placed every third plat, i.e., every variety was adjacent to a check. Each variety was replicated nine times.

According to the ability of stooling, the amount of seed per row in direct planting at Nanking was 12 grams; while at Hanchow and Wufu it was 12 grams for early rice, 10 grams for medium late, and 8 grams for late varieties. In transplanting there were 28 hills per row in all three places with 8 plants per hill at Nanking, and 8, 7, and 4 plants for the early, the medium late, and the late varieties, respectively, at Hangchow and Wufu.

Student's method was used for the interpretation of the results. The average yield of the three rows per plat was determined and converted from grams into bushels per acre for the plat. The yield of a variety was compared with the actual yield of an adjacent check and also with that of its theoretical check, which was calculated by the grading method. In case there was a great difference in yield between the two checks, the use of the theoretical check seemed better.

In the transplanting method the seedlings were grown in the seedbed for about a month before transplanting. In the direct planting method an effort was made to sow the seed the same day when the seed was sown for transplanting, but direct planting at Nanking in 1930 and 1931 was delayed from 3 to 4 weeks by rain. This long delay seems to be one of the chief causes for the non-agreement of the results of the two plantings. In the direct-planted material skips were noted in some of the rows during the seedling stage. The small skips were filled up by the stooling of the adjacent plants, but some of the larger skips were not entirely filled at Nanking. The stand of the direct-planted rice at Hangchow was fair, while that at Wufu was perfect. The stand of the transplanted rice was usually perfect. The stand had a great deal to do with the results of yield. The percentage of heading of each variety was estimated in two or three of the replicated series.

The percentage of damage done by the stem borer was determined for the two series of each variety in the two plantings at Nanking in 1931. One hundred culms of each series were taken at random after threshing and each culm examined. Those culms showing an entrance hole of the borer and having the excreta inside were considered damaged. Usually the damaged culm had an empty head.

RESULTS AT HANGCHOW AND WUFU

At Hangchow and Wufu direct planting was made three times for each variety except for the early sorts at Hangchow and the late varieties at Wufu, as shown in Table 1. The order of heading among the early varieties was the same regardless of the date or the method of planting (Table 2). Although the date of the second direct planting was the same as the sowing of the seed for transplanting, the heading of the transplanted rice was 20 to 25 days earlier. Transplanting may have hastened heading in the early rice, but this early heading might also have been due to the fact that low temperatures in April may have checked the seedlings of the direct planting series, while the seedlings on the seedbed for transplanting were crowded together and thus had a more favorable environment. Moreover, in the small seedbed the water was drained off on fine days and put back on at night to maintain a warmer temperature. It was also noted that transplanted rice headed more uniformly than direct-planted rice. This might be due to the fact that only the good seedlings were transplanted, which would naturally cause greater uniformity in growth, while in the direct-planted material both good and weak seedlings were left without selection or elimination.

TABLE 1.—*Dates of direct planting and transplanting at Hangchow and Wufu, 1931.*

Location	Variety	Direct planting			Transplanting*
		I	II	III	
Hangchow	Early	Apr. 13			Apr. 11
Hangchow	Medium late	May 3	May 17	June 5	May 17
Hangchow	Late	May 2	May 17	June 5	May 17
Wufu	Early	Mar. 28	Apr. 8	Apr. 18	Apr. 6
Wufu	Medium late	Apr. 23	May 4	May 14	May 4
Wufu	Late	May 14	May 27		May 27

*Dates of sowing the seed on the seedbed.

TABLE 2.—*Comparison of dates of heading of direct-planted and transplanted rice, Wufu, 1931.*

Variety No.	Direct planting			Transplanting
	I	II	III	
		Early		
Check	July 30	Aug. 5	Aug. 5	July 10
1	July 27	Aug. 3	Aug. 3	July 5
2	July 27	Aug. 3	Aug. 3	July 5
3	July 30	Aug. 5	Aug. 5	July 14
4	July 30	Aug. 5	Aug. 5	July 14
		Medium Late		
Check	Sept. 1	Sept. 4	Sept. 10	Sept. 12
2	Aug. 27	Sept. 1	Sept. 7	Sept. 1
1	Aug. 12	Aug. 18	Aug. 18	Aug. 18
3	Sept. 7	Sept. 12	Sept. 14	Sept. 12
4	Sept. 10	Sept. 10	Sept. 12	Sept. 10
		Late		
Check	Sept. 20	Sept. 24		Sept. 24
1	Sept. 1	Sept. 7		Sept. 7
4	Sept. 16	Sept. 22		Sept. 18
3	Sept. 18	Sept. 22		Sept. 20
2	Sept. 14	Sept. 20		Sept. 16

In the first and the second direct plantings, the 10 days' difference in planting resulted in a difference of 4 to 8 days in heading, while the third planting showed a very slight difference in comparison with the second.

The medium late varieties of the different plantings at Wufu followed the same order of heading. The 10 days difference between the first, second, and third direct plantings resulted in 4 to 6 days difference in heading. Variety 1 of medium late rice was the earliest in that group and headed at the same time in the second and third direct plantings. The late varieties of the different plantings also followed the same order of heading. The difference of 10 days between the first and second direct plantings gave about 5 days difference in heading. The transplanted rice headed a few days earlier than the second direct-planted rice.

The comparison of the heading dates between the transplanted and direct-planted rice at Hangchow is shown in Table 3. The heading time of the transplanted early rice was from a few to 10 days earlier than that of the direct-planted rice. This difference was not so great as the 20 to 25 days difference in a similar case at Wufu. The climatic difference between the two places might be a factor in this instance. On account of difficulty of getting on the land in time, the seedbed of the early rice at Hangchow was not so well prepared and cared for as at Wufu. The growth of the seedlings in the seedbed at Wufu was more rapid than at Hangchow and resulted in earlier transplanting and earlier heading. A similar order in the heading of the varieties was observed in the two places.

TABLE 3.—*Comparison of dates of heading of direct-planted and transplanted rice at Hangchow, 1931.*

Variety No.	Direct planting						Transplanting	
	I		II		III			
	Date	%	Date	%	Date	%	Date	%
				Early				
Check	July 21	93	—	—	—	—	July 21	100
4	July 21	93	—	—	—	—	July 21	96
2	July 21	100	—	—	—	—	July 11	100
3	July 21	93	—	—	—	—	July 21	100
1	July 21	100	—	—	—	—	July 16	100
				Medium Late				
Check	Sept. 2	100	Sept. 10	100	Sept. 18	57	Sept. 18	100
2	Aug. 14	100	Aug. 19	100	Sept. 2	100	Aug. 19	100
4	Sept. 7	86	Sept. 12	100	Sept. 12	100	Sept. 12	100
1	Sept. 2	100	Sept. 10	100	Sept. 18	50	Sept. 7	100
3	Sept. 7	88	Sept. 12	37	Sept. 18	12	Sept. 12	35
				Late				
Check	Sept. 18	8	Sept. 18	2	Sept. 18	0	Sept. 18	1
1	Sept. 2	100	Sept. 2	100	Sept. 18	100	Sept. 2	100
3	Sept. 18	80	Sept. 18	57	Sept. 18	2	Sept. 18	62
2	Sept. 18	100	Sept. 18	100	Sept. 18	50	Sept. 18	100
4	Sept. 18	100	Sept. 18	95	Sept. 18	30	Sept. 18	98

The 14 days difference between the first and second plantings of the medium late rice resulted in 5 to 10 days difference in heading, while the 19 days difference between the second and third plantings caused a difference of a few days to about 2 weeks in the time of heading (Table 3). Variety 4 of medium late rice showed only a slight effect of the late planting upon the heading time. This seems to be characteristic of this variety. The order of earliness was thereby changed in the third planting. In the case of the second planted rice and the transplanted rice there was only a slight effect of the two methods of planting upon the earliness.

The notes on the date of heading of the late rice at Hangchow were not quite completed but indicated a similar order of earliness between the different plantings. The 6 to 10 days difference in heading was observed in the second and third plantings. The 15 days difference between the first and second plantings gave only a slight difference in heading. In view of these results, as well as in the case of the second and the third plantings of the early rice at Wufu, it can be concluded that due to the length of day early rice is not much delayed in heading, while late rice is not greatly hastened to maturity by the time of planting.

Comparison between the yields of direct-planted and transplanted rice at Wufu is shown in Table 4. Direct-planted and transplanted early and medium late rice followed practically the same order in the yield comparison. However, the transplanted check of the early rice was lower in actual yield than that of the direct-planted rice, while the reverse was true with the varieties. The results of the first and the second lots of direct planting paralleled more closely those obtained from the transplanted series than those obtained from the third direct planting, probably due to the fact that the transplanted rice and the first and second direct-planted rice were similar in stage of growth and responded in the same way to the climatic conditions. It is advisable, therefore, to practice direct planting earlier than or simultaneously with the sowing of the seed on the seedbed for transplanting. The damage caused to the rice by the stem borer and by disease was estimated to be from 1 to 5%, but did not seriously affect the results.

A comparison of yields at Hangchow is given in Table 5. The results of the two methods agree extremely well. The damage caused by insects and disease was slight and did not seriously affect the yields. Variety 2 of the medium late rice showed contradictory results because it had a poor stand in the direct-planted field with a condition conducive to vigorous growth in the transplanted rice. The poor stand of that variety was due to the fact that the seed used was from the 1929 crop instead of 1930. In the transplanted rice the dead seed or weak seedlings were naturally eliminated during transplanting. The results of the second direct planting agreed with those obtained from the transplanted rice and were slightly better than those of the other direct plantings.

RESULTS AT NANKING

The dates of heading of each variety by direct planting and by transplanting at Nanking are shown in Table 6. The dates of sowing

TABLE 4.—*Yields in bushels per acre of direct-planted and transplanted rice at Wufu, Chekiang, 1931.*

Variety No.	Transplanting			Direct planting								
				I			II			III		
	Yield, bu.	Gain or loss over check, bu.	Odds	Yield, bu.	Gain or loss over check, bu.	Odds	Yield, bu.	Gain or loss over check, bu.	Odds	Yield, bu.	Gain or loss over check, bu.	Odds
Early												
2	44.4	5.8	>9999:1	32.7	— 8.1	9999:1	31.4	— 7.6	216:1	34.0	—11.6	9999:1
1	43.3	5.3	>9999:1	33.1	— 9.3	9999:1	31.8	— 8.5	9999:1	35.3	—10.5	9999:1
4	48.9	10.9	>9999:1	44.4	2.0	4.11:1	41.5	1.2	5.13:1	43.6	— 2.2	8.34:1
3	47.4	10.1	>9999:1	41.7	1.1	2.55:1	39.9	1.0	2.55:1	42.9	— 2.0	4.11:1
Medium Late												
4	87.4	2.1	2.00:1	59.5	14.5	9999:1	68.9	1.4	2.55:1	72.8	— 3.4	6.67:1
3	92.4	2.1	3.19:1	65.9	18.5	555:1	76.6	5.0	2.55:1	81.0	3.4	5.13:1
2	65.9	—24.4	9999:1	49.7	3.8	4.11:1	60.9	—11.4	9999:1	66.3	—11.3	5555:1
1	39.2	—35.7	9999:1	29.0	—16.2	8.34:1	41.8	—25.2	9999:1	39.7	—35.0	9999:1
Late												
3	77.7	2.0	13.6:1	70.0	0.3	1:1	61.8	6.8	344:1	—	—	—
2	69.4	— 5.1	18:1	65.1	— 5.3	18:1	53.3	— 4.0	29.8:1	—	—	—
4	78.7	4.2	6.67:1	68.9	— 1.5	2.55:1	55.2	— 2.1	4.11:1	—	—	—
1	54.6	—22.9	9999:1	54.3	—16.4	9999:1	42.6	—13.0	3332:1	—	—	—

TABLE 5.—*Yields in bushels per acre of direct-planted and transplanted rice at Hangchow, 1931.*

Variety No.	Transplanting			Direct planting								
				I			II			III		
	Yield, bu.	Gain or loss over check, bu.	Odds	Yield, bu.	Gain or loss over check, bu.	Odds	Yield, bu.	Gain or loss over check, bu.	Odds	Yield, bu.	Gain or loss over check, bu.	Odds
						Early						
4	19.0	4.5	999:1	16.5	2.1	18.0:1	—	—	—	—	—	—
2	9.8	— 1.3	5.41:1	9.5	— 4.8	3332:1	—	—	—	—	—	—
3	17.4	0.6	3.41:1	14.9	0.6	5.13:1	—	—	—	—	—	—
1	13.2	— 2.7	21.4:1	10.3	— 4.1	132:1	—	—	—	—	—	—
						Medium Late						
2	41.8	—27.0	9999:1	14.3*	—47.7	>9999:1	41.9*	—27.8	>9999:1	45.8*	—12.0	>9999:1
4	78.5	5.8	555:1	65.0	4.6	100:1	66.1	— 1.6	2.55:1	61.8	5.4	>9999:1
1	34.4	—38.3	>9999:1	51.9	— 8.3	>9999:1	55.0	—11.6	>9999:1	50.0	— 6.4	1666:1
3	72.7	4.9	216:1	60.6	— 0.4	1.55:1	64.3	— 5.9	>9999:1	48.8	— 7.9	>9999:1
						Late						
1	38.5	—29.7	>9999:1	30.7	—17.7	>9999:1	34.8	—26.4	>9999:1	33.4	—25.5	>9999:1
3	74.1	7.0	216:1	51.8	3.4	29.8:1	62.3	5.7	132:1	60.5	1.6	18:1
2	69.6	2.5	5.13:1	53.5	5.3	216:1	61.3	4.8	100:1	62.9	4.1	163:1
4	86.9	17.8	>9999:1	57.5	10.3	>9999:1	69.6	10.5	1110:1	75.5	16.6	>9999:1

*Poor stand on account of poor seed.

TABLE 6.—*Comparison of dates of heading of direct-planted and transplanted rice at Nanking, 1928-32.*

Variety No.	1928*		Percentage of heading								
			1929		1930		1931		1932		
	Direct planting	Trans-planted	Direct planting, Aug. 10	Trans-planted, Aug. 10	Direct planting, Aug. 23	Trans-planted, Aug. 5	Direct planting, Sept. 2	Trans-planted, Aug. 17	Direct planting I, Aug. 2	Trans-planted, Aug. 2	Direct planting II, Aug. 19
Check	Sept. 4	Aug. 31	100	100	87	84	75	97	64	64	56
10	Sept. 10	Sept. 10									
2	Sept. 10	Sept. 10	0	90							
3	Sept. 4	Aug. 31	100	100							
1	Sept. 10	Sept. 4	10	100	13	52					
4	Sept. 10	Sept. 4	30	100	70	59	13	71	25	22	74
5					100	100	50	70	97	98	100
6					88	100	76	97	82	88	75
7							73	100	96	98	77
8							54	99	98	87	82
9							75	100	87	85	78

*For 1928 dates of harvesting are given instead of dates of planting.

on the seedbed prior to transplanting were not available except for 1932, but the dates of transplanting were recorded and transplanting usually was done 30 to 36 days after sowing. The dates of heading were similar for the two methods of planting. In 1928 only the date of harvesting was available, and the varieties in general showed a difference of about 5 days in the time of harvesting for the two methods of planting. The test for 1929 showed a great difference in heading. Variety 2 in the transplanted field had nearly all headed by August 10, but this variety had not yet begun to head in the direct-planted field. The transplanted material of variety 1 had completed heading on the day mentioned, but the direct-planted material had just started to head. On account of the rainfall in the spring of 1930 and 1931, the direct planting was greatly delayed and consequently the direct-planted rice headed much later than the transplanted. However, the order of heading among the varieties in the two methods of planting was similar. The same varieties among the transplanted material and the first direct-planted material of 1932 headed at the same time, while those of the second direct planting headed about 10 days later.

The yields produced by the two methods of planting at Nanking are shown in Table 7. There, the gain or loss of each variety over the check was obtained by comparing the yield of a variety with the actual yield of an adjacent check. The results of the two methods of planting in 1928 were fairly parallel, while the 1929 results are contradictory. This contrast was probably due to the fact that the direct planting was delayed by the rain and that the late planting resulted in late maturity, which in turn resulted in serious damage by the stem borer.

The three transplanted varieties showed a gain over the check, while all four direct-planted varieties showed a loss. The check headed first and variety 3 second in both plantings. Variety 3 was the poorest yielding variety in the transplanted field, but the highest yielding variety in the direct-planted field. Thus, the conditions of direct planting in 1929 seemed to favor the early varieties, while transplanting favored the late varieties. As the amount of land was limited in 1929, the length of row was 12 feet and the yield per row was recorded in grams. Variety 3 showed a loss of 30.6 grams in transplanting and of 47.3 grams in direct planting. These two results were fairly close together, but the other three varieties showed a great deviation in yield under the two conditions.

The order of yield in the direct planting was exactly the same as the order of earliness, as follows: Check, variety 3, variety 4, variety 1, variety 2. The principal factor which affected adversely the direct-planted rice was the damage caused by the stem borer. The percentage of the damage in this test was not available, but in the variety test of 1929, which was also direct-planted, the damage was from 5 to 30%. The direct-planted late varieties were sometimes damaged with great loss of yield, while the early varieties often escaped damage. Since transplanted rice was earlier in heading and in maturity than that which was direct planted, it escaped damage from the borer. In addition to this factor, the stand of the direct-planted rice was not

Variety No.	1928						1929					
	Direct planting			Transplanting			Direct planting			Transplanting		
	Yield, bu.	Gain or loss, bu.	Odds	Yield, bu.	Gain or loss, bu.	Odds	Yield, grams	Gain or loss, grams	Odds	Yield, grams	Gain or loss, grams	Odds
1	60.6	—5.1	18:1	71.3	—0.7	1.6:1	295.8	—250.2	9999:1	485.7	186.6	4999:1
2	52.8	—12.9	1666:1	68.1	—3.9	6.7:1	292.3	—253.7	9999:1	517.9	218.8	768:1
3	69.7	6.4	163:1	71.2	1.1	2.5:1	495.9	—47.3	19.5:1	329.9	—30.6	3.7:1
4	62.5	10.5	100:1	80.0	8.8	100:1	440.5	—87.4	119:1	474.9	93.9	98:1
	1930						1931					
1	53.2 44.0*	6.4 0.9*	1999:1 2.5:1	79.3	—0.9	1.6:1						
4	53.9 48.6*	6.0 6.8*	832:1 9999:1	78.0	—5.7	29.8:1	8.7	—8.5	416:1	43.4	—5.2	45.7:1
5	52.1 51.3*	5.3 8.3*	163:1 1428:1	88.7	8.5	81.0:1	17.0	—1.7	10.9:1	33.1	—14.4	587:1
6	47.1 48.2*	0.6 1.2*	1.6:1 4:1	79.4	—5.2	13.6:1	21.6	1.3	18.0:1	42.7	0.9	1.7:1
7							20.3	0.0	1:1	31.1	—10.7	104:1
8							13.8	—5.4	262:1	50.3	6.9	302:1
9							20.9	1.3	8.3:1	39.5	—3.9	19.5:1
	1932											
4	53.1 32.1	—6.9 —0.9†	<9999:1 5.13:1	51.2	—7.2	9999:1						
5	52.3 31.7	—7.6 —1.8†	<9999:1 10.9:1	53.7	—6.2	555:1						
6	59.3 34.4	—0.8 1.4†	4.11:1 4.11:1	59.5	—0.7	4.11:1						
7	61.4 35.9	1.3 2.6†	4.11:1 216:1	60.6	0.4	2.55:1						
8	59.3 34.7	0.0 1.4†	1:1 49.3:1	60.0	2.4	29.8:1						
9	62.4 34.0	2.3 2.6†	132:1 81:1	60.3	2.7	37.2:1						

*Data from the advanced test.
†Data from the second direct planting.

so uniform and this might be another reason for the contradictory results of the two plantings in 1929.

In 1930, the same four varieties used in this investigation were repeated in a variety test. The damage done by the stem borer in the advanced test is shown in Table 8. The degree of the damage closely follows the order of earliness. As the record of the damage in 1930 was confined to the direct-planted rice, no adjustment of yield was made according to the amount of damage. The loss of variety 4 in the transplanted test was not statistically significant but its gain in both direct-planted tests was highly significant. The results of variety 1 in the two direct-planted tests did not agree with each other. Here, the duplicate tests of direct planting showed a degree of deviation practically as great as the results of the direct planting and transplanting. Owing to environmental influence and to certain other factors, there are some contradictory results of the two methods of planting which could not be avoided just as in the duplicate tests of the same planting.

TABLE 8.—*Damage to rice by the stem borer, Nanking, 1930–32.*

1930		1931			1932			
Strain No.	Direct planting %	Strain No.	Direct planting %	Transplanting %	Strain No.	Direct planting II %	Direct planting I %	Transplanting %
Check	17.2	Check	80.0	2.2	5	18.0	1.5	1.0
5	9.0	5	80.0	1.0	7	4.7	2.3	0.5
11	12.4	6	83.0	0.8	Check	11.2		
Check	13.9	Check	64.0	3.7	8	12.0	1.5	1.2
6	11.5	7	58.4	4.8	4	11.2	1.8	1.3
7	8.6	9	55.0	4.3	Check	20.5		
Check	19.5	Check	65.0	5.0	6	11.7	1.5	1.0
9	7.8	8	84.0	3.0	9	9.3	0.5	1.0
8	19.2	4	74.0	4.3				
Check	17.4							
1	16.3							
4	13.4							

As the time of sowing the seed in the seedbed and then transplanting it was not affected by rain, the late rice was planted at the proper time and then transplanted, maturing early enough to escape the heavy damage by the stem borer. This seems to be one of the chief causes of the non-agreement of the results between the two methods of planting at Nanking. In consideration of the damage caused by the stem borer, the adjustment of yield was tried. Taking the variety 6 in 1931 for illustration, its actual yield was 21.6 bushels per acre and the gain over the check 1.3 bushels per acre, borer damage was 19% more than the nearest check. Its adjusted gain was calculated as $1.3 + (21.6 \times .19) = x\ 5.4$. After being adjusted in this way, the yield difference of the direct-planted rice becomes rather parallel to that of the transplanted rice.

In the direct-planted rice at Nanking, uniform or perfect stand was not always obtained. In some cases this might be the cause of the non-agreement of the results between the transplanted and the direct-planted rice. The percentage of germination was first thought to be one of the causes for an un-uniform stand. A germination test of the varieties for this study was conducted with the result as shown in Table 9. The percentage of germination was practically the same for all the varieties, and therefore could not be the cause for the contradictory results. The skips of the direct-planted rice were possibly due to climatic conditions and to the preparation of land.

TABLE 9.—*Percentage of germination of the rice varieties.*

Variety	Sample I, July 24	Sample II, July 24
5	96	97
4	96	95
6	98	96
1	98	92
Check	93	96

In 1932 there were one transplanting and two direct-planting tests. The seed for the transplanting test and the first direct planting test was on April 20, while the second direct-planting was made 24 days later. The gain or loss in yield in the transplanting and the first direct-planting tests were parallel but did not parallel so closely the yield results of the second direct-planting test. The damage by the stem borer ranged from 4.7 to 20.5% in the second direct-planting test and only from 0.5 to 2.3% in the transplanting test and the first direct-planting tests. Evidently, the results might be parallel if the material is planted at the same time.

Besides the comparative value of the yield in terms of gain or loss over the check, the actual yields of the direct-planted and transplanted rice in the three places are available in Tables 4, 5, and 7. As only a few varieties were used in each test, the result of a comparison between the actual yields of the direct-planted and the transplanted rice was not different from that between the gain or loss over the check.

DISCUSSION AND CONCLUSION

The earliness of a variety as represented by the date of heading was parallel under the two methods of planting. There was a tendency for some varieties to head earlier when transplanted than when direct planted. The yield results were more complicated. In the rice belt where the conditions were favorable, the yield comparison of varieties by the two methods agreed closely, especially when the two plantings were conducted at the same time. At Nanking where the factors of rain distribution and irrigation were not so favorable for rice, the yields still agreed closely. As the stem borer usually caused more damage to late rice, the contradictory results of 1929 seemed to be due to the fact that the late rice, which was further delayed in maturity by the late direct planting, was very heavily damaged and consequently gave poor yields. Lack of uniform stand of the direct-planted rice might also be a factor in the contradictory results. The yield of the direct-planted rice of 1931, after being adjusted according to the damage, agreed more closely with the results from transplanted rice.

When seed of the first direct planting and of the transplanting tests was sown on the same day in 1932, the field results parallel and the damage by the stem borer was very slight. But the second direct-planting test of 1932, which was planted 24 days later and was damaged by the stem borer from 4.7 to 20.5%, gave yields that did not quite parallel the results of the transplanting test. Therefore, it is very important to make the direct planting at the same time that the seed is sown on the seedbed for transplanting. It was also noted in the tests of 1930, 1931, and 1932 that the difference in the amount of damage caused by the stem borer in the direct planting and the transplanting tests explained the contradictory results with respect to yield.

A method of direct planting rice has been investigated at Nanking to overcome any delay that might be caused by rain. Land for direct planting should be well prepared about 3 weeks before planting. About a week before planting and when the soil is in a good condition to work, the land should be marked and a shallow ditch opened. Then the seed can be sown even when the soil is wet. If the soil is rather wet, the seed should be covered either with straw or wood ash mixed with some dry soil which has been stored in a house in anticipation of a moist condition. The ash should be distributed as uniformly as possible. In this way direct planting will not be much delayed by spring rains.

As the rice breeder must have a very large number of selections, strains, and varieties for field test, and as transplanting in a breeding test requires 15 to 20 times as much labor as direct planting, the direct-planting method must be adopted for the first 3 or 4 years. In the advanced test, the number of strains can usually be limited to about 15 and then both direct planting and transplanting can be used. In the case direct planting is delayed, as at Nanking, the results may not agree perfectly with those obtained by transplanting, but the direct-planted strains will be given a crucial test at Nanking for the degree of susceptibility to the stem borer.

THE FERTILIZING VALUE OF GREEN MANURES ROTTED UNDER DIFFERENT CONDITIONS[1]

J. A. DAJI[2]

The practice of green manuring in general use at present consists of ploughing up or turning under a green crop and burying it directly in the soil. In China and Japan, however, the green crop is frequently composted or allowed to decompose in heaps prior to burying it in the soil. Besides the growing of regular green crops, the people of these countries make use of other plant materials as well, such as grasses and weeds, for composting. A similar method of pre-composting the green manure has been recommended by Hutchinson (3).[3] In some parts of Germany and America the green manure is spread on the surface of the soil and allowed to remain there for a period before incorporating it with the soil.

The experiments to be described here were devised with a view to find the fertilizing value of different green manures when treated in various ways before incorporation with the soil as measured by a crop of barley. A part of the experiment was carried out in pot culture and a part in the field on small plats.

POT EXPERIMENTS

Young tares, young mustard, and sugar beet tops were used as green manures. They were rapidly dried at 55° to 60° C, finely powdered, and used as such. Table 1 shows the chief manurial ingredients contained in each material.

TABLE 1.—*Composition of green manures expressed on 100 grams of dry matter.*

	Young tares	Young mustard	Sugar beet tops
Total organic matter (loss on ignition)	66.60	73.62	81.57
Iron and aluminium oxides, $Fe_2O_3 + Al_2O_3$	4.35	2.42	2.24
Lime, CaO	2.11	4.16	2.63
Magnesia, MgO	1.08	0.48	0.92
Potash, K_2O	2.90	3.85	5.98
Phosphoric acid, P_2O_5	1.32	1.61	1.18
Nitrogen	3.70	3.65	2.74

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[2] Graduate Student. The author wishes to express his indebtedness to Sir John Russell for placing the facilities of the Woburn Experimental Station at his disposal where the work reported in this paper was mainly carried out, and also to the Authorities of the Bombay University for the award of the Eduljee Dinshaw Scholarship D during the tenure of which this investigation was carried out. He further wishes to record his thanks to Dr. E. M. Crowther for suggesting the problem and to Dr. H. H. Mann and Mr. E. H. Richards for very valuable assistance, advice, and guidance throughout the course of the work and in the preparation of the manuscript.

[3] Numbers in parenthesis refer to "Literature Cited," p. 475.

Thirteen sets of quadruplicate pots were set up under five different treatments. Earthenware glazed pots, 12 inches deep, were used for the purpose. The soil was brought from the headland of one of the green manure experiment fields at Woburn.

Under treatment I, 16 grams of each of the dried materials were buried in the soil at once in their respective pots. They were mixed with the upper 3 inches of the soil only and were allowed to rot there for 64 days. This treatment corresponds to the usual practice of green manuring. Under treatment II, similar quantities of the same three manures were spread on top of the soil and allowed to decay for the same length of time as under treatment I and were then buried in the top 3 inches of the soil 2 weeks before sowing. This treatment corresponds to the practice of cutting the green manure and allowing it to remain on the soil during autumn and winter as is done in some parts of Europe and America. Under treatment III, 64 grams of each of the materials were decayed separately in beakers with the addition of lime ($CaCO_3$, 5%) and water (70%) for a period of 54 days. Two weeks before sowing each of the materials was divided into four equal portions and each portion mixed with the top 3 inches of the soil in its respective pot. This treatment corresponds to the old Chinese custom of composting the materials before applying them to the land. Under treatment IV mixtures of artificial fertilizers were made up of sulfate of ammonia, superphosphate, and sulfate of potash, containing the same amount of nitrogen, potash, and phosphoric acid as originally present in 16 grams of each of the materials. The fertilizers were applied 2 weeks before sowing. A set of four pots served as control under treatment V. Lime was common to all the pots except those under treatment V.

Sufficient water was added to bring up the water content of the soil to about 15%. Distilled water was used throughout. The pots were placed on trucks to facilitate transport and were re-randomised frequently.

A separate lot of each of the three manures kept for decomposition as under treatment III showed the following changes:

	Total nitrogen Initial %	Total nitrogen Final %	Loss of dry matter %	Loss of nitrogen %
Young tares	3.70	2.97	32.5	45.8
Young mustard	3.65	2.72	34.8	50.9
Sugar beet tops	2.74	1.61	38.2	63.5

A fortnight after the different manures had been buried, 12 seeds of Plumage Archer barley, having an average uniform weight, were sown in each pot. Six weeks later the seedlings were thinned to six plants per pot.

RESULTS AND DISCUSSION

Some of the more important data showing the performance of the crop during its growing stage are represented in Figs. 1 and 2.

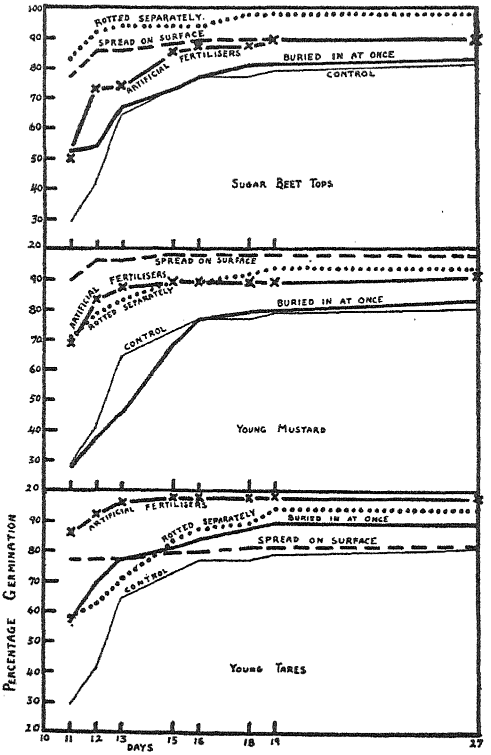

FIG. 1.—Effect of differently treated green manures on germination of barley seed.

With the exception of young mustard under treatment I, all three green manures in whatever way they were applied to the soil accelerated the germination of the barley seeds considerably. Treatment II had a very marked effect on germination as compared with treatments I and III. This acceleration is very probably due to the more uniform moisture conditions of the soil under this treatment since the manures spread on the surface of the soil were sprinkled with water more frequently in order to allow their decomposition to take place. The beneficial effect of the green manures on the germination of the barely seeds is not easy to explain. It must be mainly due to a physical improvement of the soil rather than to any chemical changes brought about by the green manures as the germinating seeds, apart from the soil moisture and soil air, do not make use of any soil constituents.

The manurial treatments have a most marked effect on the tillering capacity of the crop. Not only do they show better tillering than the control, but also there are marked differences among the manurial treatments themselves. Though young mustard and sugar beet tops under treatment III lost more nitrogen than young tares during the preliminary rotting, yet they encourage more tillering. It is possible that the residual nitrogen in these two manures was in a state of greater availability than in young tares. Treatment I is superior to the other two treatments in the case of all the three green manures. The artificial fertilizers give by far the greatest number of tillers, greater even than their corresponding organic fertilizers. They, however, show no difference in the tillering capacity among themselves.

Although all the green manures increased the height of the crop they did not show any significant difference due to the various ways in which they were applied. Similar results were obtained in the case of ear emergence.

In Tables 2 and 3 are given the yield of grain and straw, respectively, as the mean of four replicates, together with their standard error (2). It will be seen that the application of green manures has increased the crop yield from 27% to 116% in the case of grain and from 35% to 92% in the case of straw.

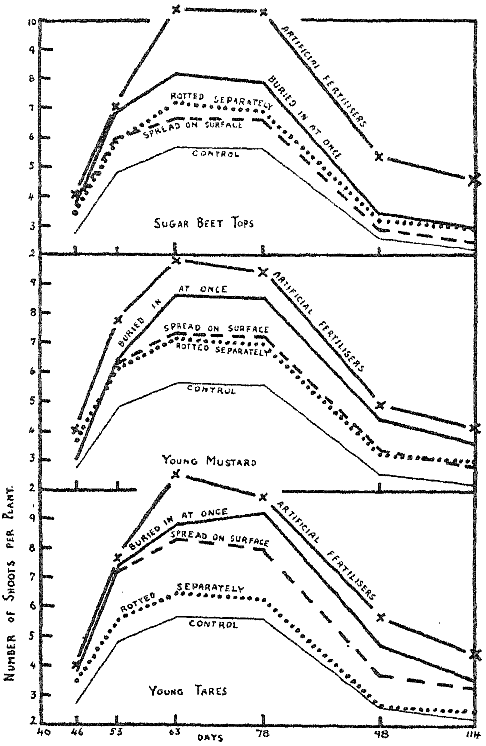

FIG. 2.—Effect of different treatments of green manures on the tillering capacity of barley.

All the treatments give significantly higher yields than the control, except sugar beet tops under treatment II. When the results of the effect of the three different ways of treating the green manures are compared as a whole, as measured by the means of the three manures, it will be noticed that treatment I is decidedly superior to the other two treatments which are almost alike. Among the manures, as measured by the mean of treatments I, II, and III, young tares show as good results as young mustard, but they are both superior to sugar beet tops. Artificial fertilizers give very much higher yields of barley than corresponding organic manures, but they show no difference in yield among themselves.

TABLE 2.—*Yield of barley grain in grams under various green manure treatments.*

Green manures	Treatments					
	None	I	II	III	Mean of I + II + III	IV
None	8.71	—	—	—	—	—
Young tares	—	18.48	16.70	12.88	16.02	23.05
Young mustard	—	18.88	14.57	15.96	16.47	21.33
Sugar beet tops	—	12.92	11.07	13.73	12.57	20.93
Mean of 3 manures	—	16.76	14.11	14.19	—	—

Standard error for mean of 4 observations = 1.4
Standard error for mean of 12 observations = 0.8

The results of the yield of barley grain agree very closely with those of the tillering capacity of the crop. The green manures give the highest yield of barley as well as the greatest number of tillers under treatment I. Young tares and young mustard produced a higher yield than sugar beet tops and also a greater number of tillers, at least in treatments I and II. The same is true with the artificial fertilizers. Straw yields agreed in general with grain yields.

TABLE 3.—*Yield of barley straw in grams under various green manure treatments.*

Green manures	Treatments					
	None	I	II	III	Mean of I + II + III	IV
None	13.02	—	—	—	—	—
Young tares	—	24.99	22.08	15.16	20.74	30.26
Young mustard	—	22.72	19.69	18.94	20.45	30.33
Sugar beet tops	—	18.37	16.22	18.15	17.58	30.64
Mean of 3 manures	—	22.03	19.33	17.42		

Standard error for mean of 4 observations = 1.3
Standard error for mean of 12 observations = 0.7

Generally speaking, the green manures when buried at once give higher yield of both grain and straw than when they are applied on the surface or when they are separately rotted. This is not surprising considering the fact that the manures lose a good part of their nitrogen in a form which would be easily assimilable otherwise during the process of decomposition when they are separately rotted. This seems to be contrary to the age-old Chinese custom of composting green manure. It is not difficult to see why it is so. The Chinese method (4) of composting is essentially different from the one adopted in these experiments. The Chinese compost their material mixed with earth and saturated with water which makes it mainly an anaerobic process of decomposition. Often the heaps of compost are plastered with clay which also makes the whole process anaerobic. Under such conditions the nitrogen of the green manure, especially if it is rich in this element, is preserved to a certain extent. The green manures under experiment were decomposed essentially under aerobic conditions, though they became anaerobic later on. The materials were rich in nitrogen and comparatively poor in cellulosic constituents. These conditions are very favorable for a rapid ammonification with the result that a large part of the nitrogen is liberated as ammonia and is readily lost.

The results are also contrary to those obtained by Hutchinson (3) by his modified method of green manuring. He obtained results with oats which showed the superiority of the fermented green manure over the usual method of green manuring with sann hemp. Apart from the fact that the nitrogen of the manure is conserved to a great extent under his conditions of fermentation, another factor plays a part here in increasing the yield of oats. The fermented manure was concentrated by application to half the area on which it was grown.

The method of spreading the manure on the soil is also conducive to a loss of nitrogen, though not to the same extent as in the other method. Boltz (1) reports a loss of about 66% of organic matter when green clover was cut and allowed to remain on the surface of the soil for a period of about 7 months. Of this loss a mere trace was retained by the soil. A similar amount of the green clover lost only 28% of organic matter during the same period of time when the material was dug in from the very beginning. Under the conditions of the experiment described in the present work, it is very likely that there was a partial loss of nitrogen during the decomposition of the materials on the surface of the soil.

That these results are correlated with the amount of nitrogen supplied by the manures under different treatments is shown by data presented in Table 4. For purposes of calculation it has been assumed that the seedlings left in the pot had the same percentage of dry matter and nitrogen as the seedlings that were thinned out. The total of these two, therefore, may be taken as an indication of the amount of nitrogen available at that stage. Although all three green manures suffered a total loss of nitrogen varying from 45% to 63% during the preliminary decomposition under treatment III, as shown previously, they supplied the greatest amount of available nitrogen during the early growth of the crop. In other words, they nitrified more easily than when applied in the other two ways.

In the case of the artificial fertilizers, though young tares and young mustard contained practically equal amounts of nitrogen in readily available form, the nitrogen uptake in the two cases was different. The low uptake in the case of the young mustard equivalent as well as in the case of the sugar beet tops equivalent is due to a lower return of dry matter as well as to a lower percentage of nitrogen in the plants. Cases are known where potash does not allow an increase of nitrogen in barley grain when large dressings of nitrogen are given. The large quantities of potash in the mustard and sugar beet tops equivalents had possibly a similar depressing effect on the nitrogen uptake in the barley seedlings.

During the later stages of crop growth, however, it is treatment I that provides the greatest amount of nitrogen in an available form, except in the case of sugar beet tops. The whole of the nitrogen present in the previously rotted sugar beet tops is in an assimilable condition as evidenced by almost a complete recovery of nitrogen in the crop. The nature of the residual material in the case of the other two green manures under this treatment is such that they do not nitrify so readily during the later stages, though they contain more nitrogen than the residual material obtained from the sugar beet tops. Nothing very definite could be said about treatment II as it was not possible to assess the extent to which the loss of nitrogen occurred. The total amount of nitrogen made available under this treatment is definitely less than under treatment I for all three manures.

TABLE 4.—*Nitrogen supplied by green manures under different treatments.*

Green manures	Dry matter in seedlings thinned out, grams	Nitrogen available at seedling stage, grams	Total nitrogen removed by crop + seedlings thinned out, grams	Nitrogen added as manure, grams	Nitrogen made available by manure at seedling stage, grams (2—its control)	Total nitrogen made available by manure, grams (3—its control)
			Control			
None	1.74	0.231	0.848	—	—	—
			Treatment I			
Young tares....	2.92	0.400	1.775	2.16	0.169	0.927
Young mustard.	2.17	0.317	1.652	2.08	0.086	0.804
Sugar beet tops.	2.18	0.308	1.207	1.56	0.077	0.359
			Treatment II			
Young tares....	2.96	0.466	1.474	—	0.235	0.626
Young mustard.	2.42	0.290	1.341	—	0.059	0.493
Sugar beet tops.	2.78	0.371	1.133	—	0.140	0.285
			Treatment III			
Young tares....	3.89	0.490	1.206	1.17	0.259	0.358
Young mustard.	3.77	0.478	1.445	1.02	0.247	0.597
Sugar beet tops.	3.95	0.464	1.413	0.57	0.233	0.565
			Treatment IV			
Young tares equivalent....	4.91	0.635	2.497	2.16	0.404	1.649
Young mustard equivalent....	3.84	0.505	2.345	2.08	0.274	1.597
Sugar beet tops equivalent....	3.13	0.406	2.363	1.56	0.175	1.515

FIELD EXPERIMENTS

This experiment was in principle similar to the one carried out in the pots. One green manure only, sugar beet tops, was used and its manurial value, when rotted under different conditions, was tested for a crop of barley. Five sets of quintuplicate 1/1000 acre plats were laid out in the Lansome Field at Woburn, the positions of the treatments in each replicate being selected at random. The treatments were as follows:

I. Sugar beet tops buried in the soil at once.
II. Sugar beet tops spread on the soil and allowed to rot there.
III. Sugar beet tops rotted separately and afterwards buried in the soil.
IV. Artificial fertilizers with N, P, and K the same as in the sugar beet tops.
V Control, no manure added.

Each plat received 18 pounds of fresh sugar beet tops chopped into small pieces. They were allowed to rot for 128 days under treatments I and II and for 55 days under treatment III. The mixture of artificial fertilizers under treatment IV worked out to sulfate of ammonia, 0.662 pound; sulfate of potash, 0.575 pound; and superphosphate, 0.293 pound. Lime at the rate of 0.252 pound per plat was common to all treatments except the control. The sugar beet tops rotted separately under treatment III showed a loss of nearly 66% nitrogen at the end of 55 days. The materials were given a further period of 2 weeks for decomposition after incorporation with the soil and before sowing the seeds.

Barley was sown at the rate of 3 bushels per acre in furrows opened out with a spade. On the seventh week after sowing the differences between the various treatments became noticeable and a close observation of the general appearance of each plat was taken. Each plat was given a certain mark, varying from 1 to 5, according to the performance of the crop. The number of marks assigned to treatments I, II, III, IV, and V were 16.5, 17.0, 13.0, 25.0, and 6.0, respectively. Height measurements and shoot counts were taken during the growth of the crop and are presented in Table 5. The heights are expressed in cm and are the average of five replicates and of eight measurements in each replicate taken at random. The shoot counts represent the number of shoots in 1 foot length taken at four different places in each plat at random.

TABLE 5.—*Growth measurements on plats receiving various green manure treatments.*

Treatment	Height measurements, cm			Shoot counts		
	64 days*	81 days*	99 days*	64 days*	81 days*	99 days*
Control....	14.01	57.74	79.13	41.70	31.36	22.90
I.........	17.46	64.40	88.49	46.30	35.49	26.95
II.........	16.61	66.18	82.87	45.30	35.24	23.45
III........	15.52	59.00	79.57	35.85	31.34	21.90
IV........	25.66	54.56	78.32	75.15	53.40	32.60

*Days after sowing.

During harvest the border effect was eliminated by harvesting the centre piece of each plat separately. Mean values for the yields of grain and straw, expressed in pounds, are given in Table 6.

DISCUSSION

The height measurements indicate the greater growth of the treated plats than the control. The vigor of growth in plats receiving artificial fertilizers was very great as judged by the height of the plants on the 64th day after sowing. But they soon began lodging and in order to prevent any more damage to themselves as well as to the adjoining plats, the tops were pruned off, hence the fall in height on the 81st and 99th day is noticeable. The number of shoots in

TABLE 6.—*Mean values for yields of grain and straw under various green manure treatments.*

Treatment	Yield of grain, lbs.	Yield of straw, lbs.
Control	1.56	2.35
I	1.84	3.05
II	1.84	2.97
III	1.81	2.78
IV	1.39	2.67
Standard error for mean	0.08	0.10

these plats, however, was far more than in any other plat at all the three stages. The green-manured plats, except those under treatment I, do not show any distinct advantage over the control as regards the number of tillers put forth.

The yield of grain when examined statistically shows that all the green-manured plats give a significantly higher yield than the control, but the effect of the different treatments among themselves is not significant. In this respect the results confirm those obtained with the sugar beet tops in the pot experiment. The yield of grain in the artificial fertilizer plats has fallen considerably, even less than the control. This is due to the fact that the plants in these plats, even though pruned, lodged badly owing to continuous rain and wind at a later stage with the result that much of the crop in these plats did not head at all. The figures for the yield of straw show results similar to those for the grain.

SUMMARY

1. Young tares, young mustard, and sugar beet tops had a beneficial effect on the barley crop when used as green manures. They accelerated germination, increased the tillering capacity, and gave bigger yields of grain and straw than the control. This was true of all three manures in whatever way they were applied. The same applies to the artificial fertilizers.

2. The yield of grain and straw was correlated with the tillering capacity, but was not affected by the height. The increased tillering and yield were primarily due to the fertilizing elements contained in the green manures, chiefly the nitrogen.

3. The green manures when buried at once gave higher yields of grain and straw than when they were applied to the surface or when they were rotted separately.

4. The fertilizing value of the different methods of applying the green manures depends on the abundance of available nitrogen returned by the treated manure for the use of the crop. The extent to which the abundance of nitrogen will be maintained in the treated manure depends on the nature of the green manure, the amount and nature of nitrogen originally present in the green manure, and the conditions under which the material is decomposed.

LITERATURE CITED

1. BOLTZ, G. E. Loss of organic matter in clover returned to the soil. Jour. Amer. Soc. Agron., 10: 210–214. 1918.
2. FISHER, R. A., and WISHART, J. The arrangement of field experiments and the statistical reduction of the results. Imp. Bur. Soil Sci., Tech. Comm. No. 13. 1930.
3. HUTCHINSON, C. M. A modified method of green-manuring. Pusa Agr. Res. Inst. Bul. No. 63. 1916.
4. KING, F. H. Farmers of Forty Centuries. Madison, Wis. 1911.

THE DURATION OF THE FAVORABLE INFLUENCE OF ALFALFA ON THE COTTON FIELDS OF ARMENIA[1]

KH. P. MIRIMANIAN[2]

In a previous paper[3] it was shown that under conditions prevailing in the Echmiadzin district of Armenia, with its semi-desert soils containing a small amount of organic matter and having a medium mechanical composition, the continued growing of alfalfa created many favorable conditions for the cultivation of cotton. These included an increase in the non-capillary porosity of the soil and of the exchangeable Ca, the latter increasing chiefly on account of a decrease of exchangeable Na; an increase in organic matter as a consequence of which the soil acquires an aggregate structure; an increase in the total nitrogen; and a decrease in the water-soluble salts, as well as the carbonates.

In order to determine the duration of this beneficial effect, in the beginning of 1929, the alfalfa field in which these observations had been made was planted to cotton continually up to 1933. A standard fertilizer containing phosphorous and nitrogen was applied each year. The results of four years' observations on the changes in this soil under continuous cotton are summarized in this paper. In order to compare the data with those reported previously, the same methods were used throughout.

Changes in the physical properties of the soil are shown in Table 1.

It will be seen from this table that the total porosity declined gradually from 63% to 65% in 1929 to 54% in 1932. It will be noted, too, that in the first year of cotton cultivation the total porosity in the arable horizon showed an increase.

Examining the correlation between the capillary and non-capillary porosity, it will be seen that non-capillary porosity which at first comprised nearly one-third of the total porosity has decreased considerably during the 4 years of cotton cultivation, while capillary porosity, on the contrary, increased. The specific gravity of the soil increased slightly as the result of some decline in the humus con-

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[1] Contribution from the Soil Laboratory of the Agricultural Institute of Armenia, Erivan, Armenia, U. S. S. R. Received for publication September 20, 1933.

[2] Head of the Laboratory and Professor of Soil Science.

[3] MIRIMANOFF, KH. P. Influence of alfalfa on the change of virgin soils in the cotton districts of Armenia. Jour. Amer. Soc. Agron., 22: 97–102. 1930.

TABLE 1.—*Physical properties of soil in the Echmiadzin district after 4 years of continuous cotton following alfalfa.*

Depth in cm	Specific gravity	Porosity			Water-holding capacity %
		Capillary %	Non-capillary %	Total %	
		1928, Alfalfa			
0–13	2.19	41.02	21.41	62.43	49.72
13–32	2.23	42.13	23.12	65.25	49.46
32–45	2.24	41.14	11.26	52.40	46.21
45–90	2.34	41.33	6.04	47.37	41.99
		1929, Cotton			
0–11	2.15	41.99	21.30	63.29	49.82
11–31	2.17	43.04	22.21	65.25	50.17
31–44	2.20	40.00	10.11	50.11	47.19
44–87	2.30	40.90	7.12	48.02	40.97
		1930, Cotton			
0–13	2.21	42.03	22.00	64.03	48.27
13–30	2.18	40.37	21.32	61.69	49.14
30–47	2.31	41.40	9.14	50.54	45.03
47–92	2.29	39.17	6.95	46.12	42.11
		1931, Cotton			
0–12	2.22	43.75	19.05	62.80	47.00
12–29	2.20	42.13	19.54	61.67	45.00
29–46	2.30	43.00	10.01	53.01	44.07
46–90	2.31	40.01	6.97	46.98	40.99
		1932, Cotton			
0–10	2.23	44.43	15.45	59.88	46.37
10–30	2.24	42.90	12.05	54.95	46.15
30–44	2.30	39.78	9.05	48.84	43.83
44–86	2.30	41.47	6.90	48.37	40.49

TABLE 2.—*Amount of exchangeable cations in soils of the Echmiadzin district after 4 years of continuous cotton following alfalfa.*

Depth in cm	Milligram equivalents for 100 grams dry soil				Percentage of exchangeable cations to total in 100 grams dry soil		
	Ca	Mg	Na+K	Total	Ca	Mg	Na+K
				1928, Alfalfa			
0–13	24.30	7.40	6.00	37.70	64.45	19.63	15.92
13–32	16.75	6.58	7.04	30.37	55.13	21.67	23.20
32–45	14.10	8.63	5.74	28.47	49.53	30.31	20.16
45–90	10.35	9.04	4.83	24.22	42.73	37.33	19.94
				1929, Cotton			
0–11	25.00	7.10	5.50	37.70	66.31	18.83	14.86
11–31	17.15	8.10	5.90	41.15	55.06	26.00	18.94
31–44	14.25	6.39	4.75	25.39	56.08	25.17	18.75
44–87	9.30	7.14	5.03	21.47	43.32	33.25	23.43

TABLE 2.—*Concluded.*

Depth in cm	Milligram equivalents for 100 grams dry soil				Percentage of exchangeable cations to total in 100 grams dry soil		
	Ca	Mg	Na+K	Total	Ca	Mg	Na+K
			1930, Cotton				
0–13	23.19	8.20	4.90	36.29	63.90	22.60	13.50
13–30	18.10	7.30	5.55	30.95	58.53	23.58	17.89
30–47	15.07	6.25	5.13	26.45	57.00	23.63	19.37
47–92	10.13	8.13	4.17	22.43	45.16	36.24	18.60
			1931, Cotton				
0–12	21.04	7.27	5.12	33.44	62.92	21.74	15.34
12–29	17.83	7.18	6.17	31.18	57.18	23.08	19.74
29–46	12.33	6.13	4.11	22.57	54.63	27.16	18.21
46–90	10.12	8.01	5.24	23.37	43.30	34.27	22.43
			1932, Cotton				
0–10	17.44	7.31	6.62	31.57	55.59	23.30	21.11
10–30	16.37	6.14	7.40	29.91	54.70	20.55	24.85
30–44	11.55	7.19	6.52	25.26	45.72	28.46	25.82
44–86	11.00	8.33	5.13	24.46	45.00	34.05	20.95

tent. Accompanying this change will be observed a definite decrease in the moisture-holding capacity of the soil from about 50% for 1928 to 46% in 1932.

The situation with regard to the exchangeable cations is shown in Table 2.

Close observation of the data reveals that the total exchangeable cations have declined. This may be explained by the decrease of the organic part of the absorbed soil complex which is associated with a decline in total humus. Thus, from 37.70 milligram equivalents in 1928, the total exchangeable cations declined to 31.57 milligram equivalents in 1932. Exchangeable Ca makes up the greater part of the exchangeable cations. During the first 3 years of cotton cultivation the decline in exchangeable Ca was slight, decreasing from 24.3 milligram equivalents in 1928 to 21.04 milligram equivalents in 1931. By 1932, however, it had dropped to 17.44 milligram equivalents. Exchangeable Mg showed no perceptible change, while exchangeable Na with K increased slightly. The decreasing of exchangeable Ca and the increasing of exchangeable Na results in the destruction of the aggregate state of the soil and it acquires a dispersed character. This was particularly noticeable in the fourth year of cotton cultivation.

In Table 3 are presented the results with respect to humus, N, and CO_2.

The amount of humus increased during the first year and then declined gradually from 3.12% in 1929 to 2.12% in 1932. The ratio of water-soluble humus to total humus increased slightly as a result of the increase of exchangeable Na in the absorbed complex. The total N varied with humus content. The increase in humus content and in

TABLE 3.—*Amount of humus, nitrogen, and CO_2 in soils of the Echmiadzin district after 4 years of continuous cotton following alfalfa.*

Depth in cm	Hygroscopic moisture %	Total humus %	Water-soluble humus to total humus	N %	CO_2 %
		1928, Alfalfa			
0–13	4.19	2.92	1:180	0.188	0.600
13–32	4.00	1.56	1:150	0.084	0.098
32–45	4.27	0.77	1:54	0.081	0.074
45–90	4.18	0.51	1:47	0.056	0.088
		1929, Cotton			
0–11	5.10	3.12	1:190	0.201	0.545
11–31	5.29	3.00	1:175	0.179	0.103
31–44	4.35	1.57	1:103	0.090	0.082
44–87	4.27	0.58	1:52	0.058	0.087
		1930, Cotton			
0–13	4.97	2.90	1:174	0.180	0.563
13–30	5.13	2.70	1:160	0.104	0.098
30–47	4.29	1.70	1:70	0.093	0.074
47–92	4.00	0.50	1:54	0.070	0.090
		1931, Cotton			
0–12	4.90	2.70	1:179	0.182	0.507
12–29	5.03	2.02	1:178	0.160	0.089
29–46	4.30	1.15	1:59	0.072	0.082
46–90	4.17	0.60	1:63	0.057	0.091
		1932, Cotton			
0–10	4.93	2.12	1:169	0.163	0.514
10–30	4.17	1.16	1:161	0.090	0.094
30–44	4.42	1.04	1:55	0.064	0.090
44–86	3.97	0.57	1:53	0.049	0.088

TABLE 4.—*The mechanical analysis of soil in the Echmiadzin district after 4 years of continuous cotton following alfalfa.*

Depth in cm	Fine silt 0.01–0.005 mm	Very fine silt 0.005–0.001 mm	Clay <0.001 mm
	1928, Alfalfa		
0–13	36.47	16.78	6.72
13–32	32.02	10.74	4.82
32–45	37.23	13.99	4.20
45–90	24.31	12.42	2.76
	1929, Cotton		
0–11	35.72	17.18	6.99
11–31	31.13	16.80	6.77
31–44	36.32	12.41	5.30
44–87	30.71	14.03	3.14
	1930, Cotton		
0–13	36.25	16.26	6.47
13–30	33.10	12.13	6.00
30–47	30.73	15.17	4.85
47–92	25.37	11.45	4.13

TABLE 4.—*Concluded.*

Depth in cm	Fine silt 0.01–0.005 mm	Very fine silt 0.005–0.001 mm	Clay <0.001 mm
	1931, Cotton		
0–12	35.71	16.15	6.43
12–29	36.21	12.41	5.84
29–46	32.18	14.09	4.90
46–90	27.07	13.11	3.10
	1932, Cotton		
0–10	36.22	16.47	6.70
10–30	33.17	11.03	5.10
30–44	35.44	14.20	4.80
44–86	26.69	12.27	3.13

nitrogen in 1929 may be explained by the presence of a large amount of vegetable matter which had accumulated in the soil over a period of years and which, after the first plowing, decomposed rather rapidly. Due to systematic irrigation of the land the CO_2 content is generally inconsequential and shows little variation.

The mechanical analysis of this soil, especially with regard to the fine fractions that play an important part in the absorbing complex, is given in Table 4.

It is evident from the figures given in Table 4 that there has been no perceptible change in the mechanical composition of soil during the 4 years of cotton cultivation.

Table 5 shows the changes in the water-soluble salts in the same period.

From Table 5 it will be observed that the total salts content of this soil is very low. As to the distribution of the salts, no considerable difference was observed during the 4-year period.

DISCUSSION

Thus it is to be seen that during 4 years of uninterrupted cultivation to cotton following prolonged cropping to alfalfa, this soil undergoes many changes. The first year of cotton cultivation, i. e., immediately after the plowing under of the alfalfa, the humus, total nitrogen, and exchangeable Ca increased noticeably, accompanied by a slight increase of moisture-holding capacity and total porosity. From this point on, however, these values decrease slowly with a rather sharp decline by 1932.

The data show that the favorable conditions created in the soil by prolonged cultivation to alfalfa were conserved during the first 3 years of cultivation to cotton, but that beginning with the fourth year of continuous cotton they began to disappear.

Comparing the changes in porosity, the exchangeable Ca, and the humus content during the 4 years with the yield data for the cotton, the results presented in Table 6 were obtained.

Thus, it will be seen that the yield of cotton is in perfect correlation with the changes in the soil. The 6% increase in yield in 1930 is ex-

TABLE 5.—*Percentage of elements in water extracts on dry weight basis of soil in the Echmiadzin district after 4 years of continuous cotton following alfalfa.*

Depth in cm	Dry remnant %	Solar remnant %	Loss on ignition %	Total alkalinity (H_2CO_3)	Cl	SO_3	CaO	MgO
1928, Alfalfa								
0–13......	0.0830	0.0630	0.0200	0.0390	0.0022	—	0.0212	000.10
13–32......	0.0560	0.0452	0.0108	0.0260	0.0028	—	0.0140	0.0021
32–45......	0.0625	0.0447	0.0178	0.0258	0.0036	—	0.0073	0.0016
45–90......	0.0660	0.0538	0.0122	0.0264	0.0083	—	0.0151	0.0020
1929, Cotton								
0–11......	0.0894	0.0695	0.0199	0.0370	0.0019	—	0.0303	0.0031
11–31......	0.0770	0.0642	0.0128	0.0320	0.0031	—	0.0310	0.0036
31–44......	0.0608	0.0441	0.0167	0.0265	0.0050	—	0.0089	0.0011
44–87......	0.0688	0.0555	0.0133	0.0273	0.0083	—	0.0098	0.0019
1930, Cotton								
0–13......	0.0821	0.0630	0.0191	0.0360	0.0013	—	0.0237	0.0010
13–30......	0.0711	0.0610	0.0101	0.0340	0.0020	—	0.0241	0.0012
30–47......	0.0680	0.0510	0.0170	0.0251	0.0037	—	0.0093	00.023
47–92......	0.0559	0.0439	0.0120	0.0244	0.0071	—	0.0109	0.0017
1931, Cotton								
0–12......	0.0823	0.0620	0.0203	0.0310	0.0020	—	0.0297	0.0013
12–29......	0.0705	0.0530	0.0175	0.0249	0.0017	—	0.0201	0.0015
29–46......	0.0651	0.0480	0.0171	0.0247	0.0041	—	0.0088	0.0010
46–90......	0.0541	0.0444	0.0097	0.0257	0.0053	—	0.0097	0.0025
1932, Cotton								
0–10......	0.0807	0.0643	0.0164	0.0389	0.0026	—	0.0230	0.0014
10–30......	0.0763	0.0614	0.0149	0.0345	0.0028	—	0.0264	0.0020
30–44......	0.0603	0.0500	0.0103	0.0240	0.0052	—	0.0111	0.0017
44–86......	0.0588	0.0490	0.0098	0.0210	0.0067	—	0.0094	0.0029

TABLE 6.—*Correlation of porosity, humus, and exchangeable cations to yield of cotton.*

Year	Capillary porosity %	Non-capillary porosity %	Humus %	Exchangeable Ca %	Yield of cotton with 1929 as 100
1929......	41.99	21.30	3.12	25.00	100
1930......	42.03	22.00	2.90	23.19	106
1931......	43.75	19.05	2.70	21.04	95
1932......	44.43	15.45	2.12	17.44	75

plained partly by a surplus of nitrogen from the decomposition of the alfalfa.

It may be concluded, therefore, that under conditions prevailing in the Echmiadzin district of Armenia, the favorable influence of alfalfa lasts for 3 years, but begins to decline from that point on.

An effort is now being made to determine the length of time the soils of this region should be kept in alfalfa to render them suitable for cotton production.

THE DETERMINATION OF CARBON DIOXIDE EVOLUTION IN SOIL[1]

MARK H. BROWN[2]

Since Boussingault and Lewy (1)[3] first determined the carbon dioxide content of the soil air, a number of laboratory methods have been devised for the study of amounts of carbon dioxide evolved from soil. Peterson (7) and Wollny (12) placed samples of soil in tubes, drew carbon dioxide-free air through them, and determined the carbon dioxide evolved.

Stoklasa and Ernest (10) used the same principle in their studies and were the first to attempt careful control of the conditions under which the experiments were conducted. The aeration principle has been used by Neller (6), Potter and Snyder (8), Marsh (5), and Waksman and Starkey (11).

Leather (3), adapting the method of Deherain and Demoussy (2), incubated a sample of soil in a bottle and determined volumetrically the carbon dioxide evolved at the end of a 22-day period.

Lundegardh (4) incubated the soil in a 1-liter Erlenmeyer flask and Smith and Brown (9) modified the method further by incubating a sample of soil in a 1-liter Erlenmeyer flask equipped with a mercury seal stirrer and determining the carbon dioxide after a period of 18 to 24 hours.

PROCEDURE

Although some investigators have controlled the moisture and temperature conditions under which carbon dioxide evolution studies have been made, the effect of different degrees of aeration on carbon dioxide evolution has not been studied. The experiment described here was set up in the laboratory to determine the carbon dioxide evolution from soil under conditions of continuous aeration, continuous accumulation, and "aeration-accumulation."

The soils were all made up to the same moisture content at the start of the experiment, and the temperature was carefully controlled by incubating in a constant temperature water bath at 25°C ± 0.1°. The study was carried out according to the following plan.

About 1,000 grams of Carrington loam were passed through a 2-mm sieve, carefully mixed, and six samples of the soil equivalent to 100 grams of air-dry soil were weighed out. One gram of finely ground straw was carefully mixed with each sample which was then placed in a calibrated 1-liter Erlenmeyer flask and the moisture content of the soil made up to 30%. The straw was added as a source of slowly decomposable organic matter in order to stimulate carbon dioxide production so that any possible differences due to the methods of determination would not interfere with the accuracy of the results. The three sets of duplicate flasks were then immersed up to the neck in the water bath and incubated at 25°C. The amounts of carbon dioxide produced by the soil in each flask were determined at the end of each 24-hour period for 10 days when the carbon dioxide production apparently reached an equilibrium and the experiment was discontinued.

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[1] Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Part of a thesis submitted in partial fulfillment of the requirements for the degree of doctor of philosophy, Iowa State College. Received for publication September 22, 1933.

[2] Assistant in Soils. The author wishes to express appreciation to the American Cyanamid Company, which made this work possible; to Dr. P. E. Brown, for aid in outlining the problem and in preparing the manuscript; and to Dr. F. B. Smith, for guidance and aid in the laboratory work.

[3] Numbers in parenthesis refer to "Literature Cited," p. 485.

The study of the aeration method was carried out according to the procedure proposed by Waksman and Starkey (11). The air passing over the soils was drawn from a common distribution chamber. The air passing into this chamber was freed of carbon dioxide and ammonia and made up to a uniform moisture content by bubbling successively through two 50% solutions of potassium hydroxide and a 10% solution of sulfuric acid. An ordinary water pump furnished the suction and a suction chamber provided with a mercury valve was a great aid in maintaining a uniform rate of flow. A flow meter (calibrated to 5 liters per hour against a wet test meter) placed in each line between the absorption train and the suction chamber insured an equal flow of air over each sample. The absorption train for each line consisted of four 250-cc extraction flasks connected in series, each of which contained 100 cc of 0.02 N potassium hydroxide.

The inlet into each flask was a glass tube which reached to the bottom of the flask and terminated in a small bulb in which 3 or 4 fine holes had been made. This type of absorption flask was more satisfactory than the standard absorption towers. The inlet bulbs broke up the stream of air into small bubbles insuring efficient absorption of the carbon dioxide, and the titration of the excess base could be carried out in the flask. Before titrating the excess base, sufficient barium chloride solution was added to precipitate all the carbonate present and leave a slight excess. The excess base was then titrated with 0.1 N hydrochloric acid using phenolphthalein as an indicator, the titration being made quickly.

The study by the accumulation was carried out according to the procedure proposed by Smith and Brown (9). The flasks used in this study were closed with rubber stoppers which were provided with inlet and outlet tubes and a mercury seal stirrer. At the end of each 23- to 24-hour period, the air in the flask was stirred thoroughly by means of a small electric motor attached to the mercury seal stirrer and the percentage of carbon dioxide determined by means of a modified Haldane gas analysis apparatus. After sampling the air in the flask, the inlet and outlet were closed and the carbon dioxide allowed to continue to accumulate.

A U-tube containing soda lime was connected to the inlet of the flask at the time of sampling to prevent the entrance of any carbon dioxide from the laboratory air. The parts of the Haldane apparatus[4] used were mounted on a ½ inch cypress board 5 by 18 inches which fitted tightly inside a cylindrical museum jar used as a water bath.

[4] Designed and assembled by Dr. F. B. Smith and the writer.

The apparatus was almost completely immersed in water and circulation provided between the large water bath and the bath of the Haldane apparatus by an air lift pump and a siphon. This arrangement proved very satisfactory and greatly increased the speed with which readings could be made. The micro-pipette in this apparatus was calibrated in 0.01 cc divisions. The concentration of carbon dioxide in the air in these flasks reached 10% at the end of the sixth day and over 12% at the end of the experiment. Difficulty was experienced in reading such high concentrations as the air drawn into the incubation flask when a sampling was taken caused a marked lowering of the concentration of carbon dioxide in the succeeding sample. While the readings recorded for the seventh, eighth, and ninth days showed an irregular variation in the production of carbon dioxide, it is felt that the last reading made was accurate and that the amount of carbon dioxide produced during the experiment shows the actual production.

The procedure used in the accumulation-aeration method was the same as that described in the preceding paragraph with this variation. Each day after determining the amount of carbon dioxide, the outlet of the flask was connected to a water pump and the air in the flask replaced with laboratory air by flushing out vigorously for 15 minutes. The inlet and outlet were then closed and accumulation allowed to take place for another day. The milligrams of carbon dioxide produced per 100 grams of soil in 24 hours were calculated as follows:

$$\text{Volume} = \text{vol. of flask} - \left(\frac{100}{\text{sp. gr.}} + \text{vol. of moisture contained}\right)$$

$$\text{Volume} \times \%\,CO_2 \times \text{density} = CO_2 \text{ in flask}$$

$$\frac{(CO_2 \text{ in flask}) - (CO_2 \text{ in laboratory air}) \times 24}{\text{Time in hours}} = \text{weight } CO_2 \text{ per } 100$$

grams of air-dry soil.

As numerous tests showed that the amount of carbon dioxide in the laboratory air was about 0.03%, this value was used in making the calculations. The assumption was also made that the rate of carbon dioxide production during the first 24 hours was quite uniform.

RESULTS

The amounts of carbon dioxide produced each day are recorded in Table 1. In the case of the accumulation-aeration method, deductions have been made for the carbon dioxide in the laboratory air; and in the case of the results of the accumulation method, corrections have been made for the amounts of carbon dioxide used in the daily determinations. The percentage of moisture present in these soils at the end of the 10 days is also reported.

These results show that the amount of carbon dioxide produced by soil under the different conditions used in this study were the same for the first 5 days. During the last 5 days the amount produced under the aeration method decreased when compared with the amounts produced by the other two methods, probably due to the decrease in moisture content. No differences were noted between the amounts of carbon dioxide produced under the accumulation and the accumulation-aeration conditions.

TABLE 1.—*Mgm of carbon dioxide produced in 24 hours by duplicate samples of 100 grams of air-dry soil by three laboratory methods.*

Date	Accumulation method		Accumulation-aeration method		Aeration method	
Dec. 30	39.28	43.33	31.64	31.50	31.30	30.00
31	35.91	32.21	44.38	41.02	31.95	29.35
Jan. 1	53.26	53.01	56.89	56.50	51.75	51.15
2	37.41	34.56	35.98	34.63	33.95	32.85
3	24.85	22.31	27.39	27.81	22.70	18.75
4	23.65	21.09	21.79	22.12	15.65	14.35
5	17.80	13.63	18.41	18.28	11.65	11.10
6	16.68	14.14	15.69	15.49	11.65	11.25
7	17.00	19.84	13.86	13.91	10.15	8.40
8	13.00	17.23	14.15	14.50	6.85	5.50
Total, mgm	278.84	271.34	280.18	275.76	227.60	212.73
Moisture at end of experiment, %	32.0	32.0	23.0	23.0	17.0	13.0

DISCUSSION

Two of the questions in mind when the experiment was planned were these:

1. Will the aeration of a sample of soil according to the procedure noted stimulate carbon dioxide production?

2. Will the amount of carbon dioxide in the air above the soil have any effect on the production in the soil and its diffusion from the soil?

The results reported in Table 1 open up some interesting questions for further study. This table shows clearly that with the accumulation and accumulation-aeration methods, no differences were observed in amounts of carbon dioxide produced when the air of the flask was changed each 24 hours, and when the carbon dioxide was allowed to accumulate from day to day until the concentration in the air above the soil reached slightly over 12%. The data secured with the aeration method indicate that had the moisture content of these soils been maintained, the amounts of carbon dioxide produced probably would have been the same as those produced by the other soils.

These results indicate that the production of carbon dioxide may not be affected by concentrations of this gas up to 12% in the air above the soil and that constant aeration at 5 liters per hour did not stimulate production. This indicates three possibilities. First, that carbon dioxide may not inhibit the action of certain micro-organisms which produce it when present in the air in concentrations up to 12%. As the amount of air in a loam soil at optimum moisture conditions occupies about one-fourth of the total volume, it is possible that in a normal soil the micro-organisms live and function under much higher concentrations of this gas. Second, that the inherent properties of the soil and its moisture content affect the rate of production and consequently the diffusion of this gas to a much greater extent than its concentration in the air above the soil. Third, assuming that the gas diffused quite rapidly into the air above the soil, the rate of action of the micro-organisms may not be affected by rapid diffusion of this gas.

The accumulation-aeration method is by far the most desirable method of the three to use in carbon dioxide studies. The difficulty of determining accurately the percentage of carbon dioxide in high concentrations has been discussed. The data reported in the aeration study required 80 titrations, each of which presented a chance for error. In addition, the suction pump required attention several times each day to insure a uniform rate of aeration. These tests show that no differences occurred in the amounts of carbon dioxide produced when the soil was aerated constantly or intermittently or when the carbon dioxide was allowed to accumulate up to a concentration of 12% in the air above the soil.

LITERATURE CITED

1. Boussingault, M. M., and Lewy. Sur la composition de l'air confine dans la terre vegetale. Ann. Chim. Phys., 37 : 5–50. 1853.
2. Deherain, P. P., and Demoussy, M. E. Sur l'oxydation de la matiere organique du sol. Ann. Agron., 22 : 305–337. 1896.
3. Leather, J. W. Soil gases. Mem. India Dept. Agr., Chem. Ser., 4 : 85–134. 1915.
4. Lundegardh, H. Carbon dioxide production and crop growth. Soil Science, 23 : 417—454. 1928.
5. Marsh, F. S. A laboratory apparatus for the measurement of carbon dioxide evolved from soils. Soil Science, 25 : 253–262. 1928.
6. Neller, J. R. Studies on the correlation between the production of carbon dioxide and the accumulation of ammonia by soil organisms. Soil Science, 5 : 225–242. 1918.
7. Peterson, P. Über den Einfluss des Mergels auf die Bildung von Kohlensäure und Salpetersäure im Ackerboden. Landw. Vers. Stat., 13 : 155–175. 1871.
8. Potter, R. S., and Snyder, R. S. Carbon dioxide production in soils and carbon and nitrogen changes in soils variously treated. Iowa Agr. Exp. Sta. Res. Bul. 39. 1916.
9. Smith, F. B., and Brown, P. E. Methods for determining carbon dioxide production in soils. Iowa Agr. Exp. Sta. Res. Bul. 147. 1932.
10. Stoklasa, J., and Ernest, A. Über den Ursprung, die Menge, und die Bedeutung des Kohlendioxide im Boden. Centbl. Bakt. Abt. II, 14 : 723–736. 1905.
11. Waksman, S. A., and Starkey, R. L. Microbiological analysis of soil as an index of soil fertility: VII. Carbon dioxide evolution. Soil Science, 17 : 141–161. 1924.
12. Wollny, E. Untersuchungen über den Kohlensäuregehalt der Bodenluft. Landw. Vers. Stat., 25 : 373–391. 1880.

RENOVATION OF AN OLD LAWN[1]

F. A. Welton and J. C. Carroll[2]

Whenever a lawn becomes so contaminated with weeds that there is not enough grass left to make it worthwhile to save, the usual plan of renovation is to spade or plow up the ground, fertilize, and reseed. To work over the soil not only involves much labor and expense, but oftentimes, on account of location of shrubbery and plantings of various kinds, this procedure is not only difficult but impractical. Most weeds can be killed with herbicides of one kind or another; however, many of the more effective of these materials remain in the soil for a considerable time and thus interfere with subsequent reseeding. For this reason, they are unsatisfactory for use on lawns. If the weeds could be killed by the use of some herbicide that would not remain long in the ground and if the work could be done in the late fall or winter (early enough, however, so that the herbicide would not interfere with early spring seeding), then the renovation could be effected not only with a minimum of labor but at a time of year when the attending unsightliness of the operation would be least objectionable. Although a well prepared seedbed is desirable, successful lawn seedings can often be made without previous preparation of seedbed, providing the work is done early in the spring, usually sometime in March when the ground is in a honeycombed condition, depending upon subsequent freezing and thawing to cover. If, for any reason, the ground does not honeycomb readily, coverage of the seed may be effected either by raking or by broadcasting materials, such as good garden loam or peat moss, over the surface.

To fulfill the required conditions, sodium chlorate[3] seemed promising, since previous experiments had shown that it would kill practically all weeds commonly found on lawns, including dandelions which are probably the most obdurate of them all. Accordingly, an experiment was started for the purpose of determining if sodium chlorate applied in the fall or winter would kill lawn weeds, and, if so, the rate and time of application required to accomplish the desired end with one treatment.

For the experiment, an area badly infested with weeds, chiefly dandelions, was selected (Fig. 1). The land, a Wooster silt loam, sloped gently to the west and was naturally well drained. Thirty plats, each containing 100 square feet (5 by 20 feet), were laid off in a continuous series, leaving a 1-foot aisle between. Five plats were sprayed each month, beginning in September and continuing up to and including February. On each date, the chlorate was used in five strengths, *viz.*, 8, 12, 16, 20, and 24%. One gallon of solution was put on each plat in the form of a fine spray by means of a hand sprayer. The dates of application were September 29, October 27, November 19, and December 20, 1930, and January 24 and February 24, 1931.

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[1] Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication, September 18, 1933.

[2] Associate and Assistant, respectively.

[3] In the use of sodium chlorate, consideration should be given to the fact that under certain conditions it may become a grave fire hazard.

In March the plats were raked over to remove refuse, fertilized with a 4-12-4 fertilizer at the rate of 20 pounds per 1,000 square feet, and then on March 17 seeded at the rate of 4 pounds per 1,000 square feet with a mixture consisting of 3 parts by weight of Kentucky bluegrass, 1 part redtop, and ¼ part of white clover.

With the coming of spring and during the ensuing year, it was possible to note the effect of the chlorate not only on the killing of the weeds, but also on the stand and subsequent behavior and growth of the new seeding. The chlorate was effective in killing the weeds on all dates of application, but on some dates a stronger solution was required than on others, the few inconsistencies being due presumably to the prevailing soil and climatic conditions at the time of application. With few exceptions, a strength of 12% (approximately 1 pound per gallon) was sufficient to kill practically all the weeds. Other experiments made in other years, however, show that on the Wooster soil close to sandstone, a stronger solution (1½ or 2 pounds per gallon) may be needed for such weeds as dandelions and yarrow. Experience indicates also that better results are obtained from applications made on unfrozen than on frozen ground. On the latter, especially if the ground is sloping, much of the solution may be lost.

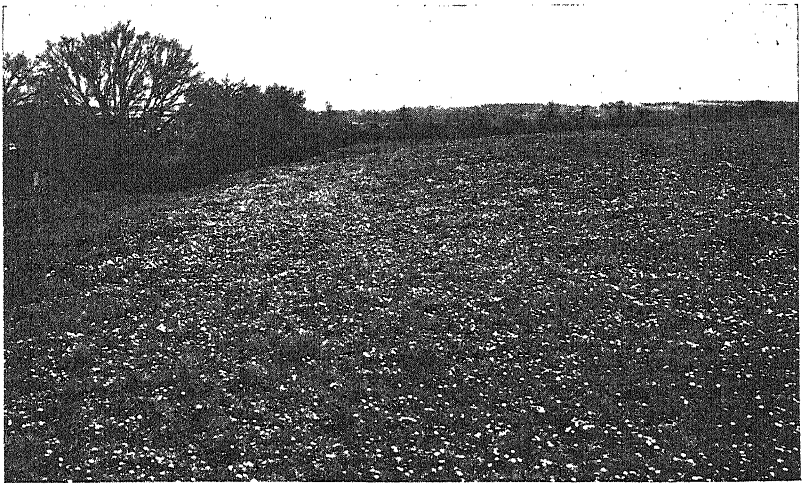

FIG. 1.—Area before treatment—mostly dandelions.

A good stand of grass was obtained on all the plats sprayed before the first of the year. A little yellowing in spots, however, occurred on some of the plats treated in December, but this proved to be a temporary situation only for the plants soon took on a green color, became thrifty, and developed a good stand. On the January-treated plats there was considerable yellowing of the grass and the stand was a little thin, but, with the passing of time, it materially improved and a year later it was quite satisfactory. On the February-treated plats, a very poor stand was obtained, many bare spots remaining on the plats receiving the stronger chlorate solutions. This seeding was altogether unsatisfactory.

An examination of the soil for chlorate during a brief period following the time of seeding revealed a close correlation between the residue of this material remaining in the soil and the stand of plants obtained. For this purpose, soil samples were taken April 1, May 1, and June 1, 1931, to depths of 0 to 4, 4 to 8, 8 to 12, and 12 to 24 inches on the plats receiving the weakest (8%) and the strongest (24%) solutions. The method described by Yoe[4] was used to determine the chlorate. The results obtained, expressed in p.p.m. of air-dry soil, are shown in Table 1.

TABLE 1.—*Sodium chlorate in p.p.m. remaining in soil at various depths and after various intervals of time.*

Date of sampling	8% solution				24% solution			
	0–4 in.	4–8 in.	8–12 in.	12–24 in.	0–4 in.	4–8 in.	8–12 in.	12–24 in.
Sept. 29 Application								
April 1	0	0	0	0	0	0	0	Trace
May 1	0	0	0	0	0	0	0	0
June 1	0	0	0	0	0	0	0	0
Oct. 27 Application								
April 1	0	0	0	Trace	0	20	24	30
May 1	0	0	0	0	0	0	0	0
June 1	0	0	0	0	0	0	0	0
Nov. 19 Application								
April 1	0	0	Trace	29	0	Trace	71	78
May 1	0	0	0	0	0	0	0	0
June 1	0	0	0	0	0	0	0	0
Dec. 20 Application								
April 1	Trace	Trace	19	31	Trace	Trace	52	76
May 1	0	0	0	0	0	0	0	0
June 1	0	0	0	0	0	0	0	0
Jan. 24 Application								
April 1	29	21	20	Trace	18	41	56	34
May 1	0	0	0	Trace	0	Trace	Trace	50
June 1	0	0	0	0	0	0	0	0
Feb. 24 Application								
April 1	40	27	Trace	0	122	29	22	18
May 1	42	27	Trace	0	82	116	114	44
June 1	0	0	0	0	29	21	18	0

Prior to the December applications, no chlorate was found in the surface 4 inches of soil, not even a trace on the plat receiving the strongest solution. On the December-treated plats, a trace of chlorate was found in the first two depths on April 1, but nothing later in those two zones. On the January-treated plats, there was some chlorate remaining in the surface 4 inches on April 1, which probably was responsible for the slightly poorer stand of grass obtained on this group of plats to which reference has already been made. On the February-treated plats, a considerable quantity of chlorate remained on May 1 in the surface 4 inches of the plat treated with the 8% solution, and it had not disappeared entirely on the plat treated with the 24% solution as late as June 1. As already stated, the stand of grass obtained on this group of plats was poor and spotted. These analytical results taken in connection with the growth of grass indicated that on a type of soil like the Wooster silt loam sodium chlorate may be expected to be sufficiently leached out of the soil to a depth of 4 to 8 inches, the zone in which most of the grass roots develop, within approximately 3 months after the application is made. Substantially the same results were obtained in three similar tests representing two winters. Where sandstone comes close to the surface, the chlorate apparently leaches out more rapidly than on the Wooster silt loam, for on May 1, 1933, no trace of chlorate was found to a depth of 3 feet in the Wooster soil shallow to sandstone sprayed in November, 1932; whereas on the deeper Wooster silt loam sprayed at the same time, 25 p.p.m. were found in the second foot and 9 p.p.m. in the 8- to 12-inch zone. Apparently, the chlorate is less effectively retained in a soil shallow to sandstone than in deeper silt loam, and thus to attain an equally effective killing a stronger solution, as before stated, is required on the former than on the latter soil. The longer the interval between the time of applying the chlorate and the time of seeding, however, the more complete will be the decomposition of any vegetation that may be on the surface and hence the greater the ease with which the ground can be satisfactorily cleaned for seeding. Late September or early October is a desirable time, providing the resulting discolored and dead vegetation is not too great an objectionable factor.

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[4] Photometric chemical analysis, Vol. I, Colorimetry.

Whether it is worthwhile to eradicate dandelions on a lawn surrounded by territory which is badly infested may be a question, but in a good stand of grass they gain a foothold slowly, as indicated in Fig. 2. Topdressing regularly with sulfate of ammonia is an aid in preventing their establishment, as illustrated in Fig. 3. Young buckhorn plants come in readily after treatment; hence, this procedure for the control of this pest is disappointing unless precautions have previously been taken for a period of years to prevent the deposition of seeds.

If sodium chlorate is applied with care, it will not injure adjoining flowers or shrubs. It is sometimes sprayed on borders or pathways to control weeds, as shown in Fig. 4. Neither does it seem to be harmful to trees, at least to those which are well developed. No injury to a dogwood, maple, oak, or red cedar tree has yet been observed under which sodium chlorate was applied as a dry salt at the rate of 1 pound per 100 square feet on December 8, 1930.

SUMMARY

1. Sodium chlorate applied in the fall or winter will kill practically all weeds commonly found on lawns, including dandelion, buckhorn, broadleaved plantain, yarrow, and sorrel.

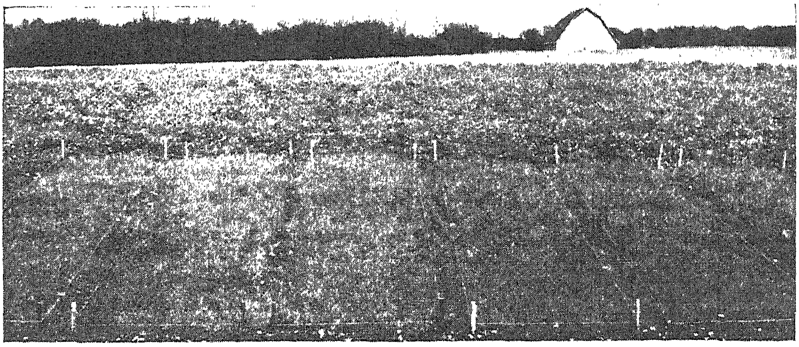

FIG. 2.—A portion of same area after treatment. From left to right, sprayed Sept. 29, 1930, with 8%, 12%, 16%, 20%, and 24% solutions of sodium chlorate. Seeded March 17, 1931. Photographed May 9, 1932.

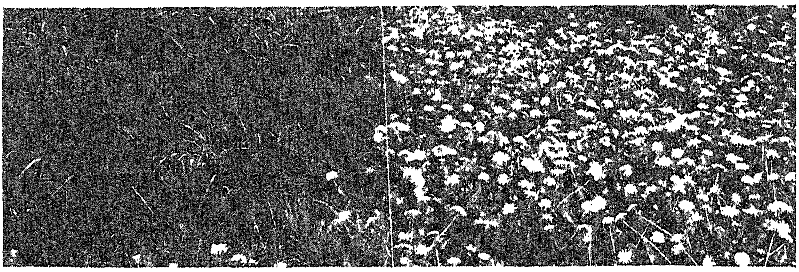

FIG. 3.—Five monthly topdressings of sulfate of ammonia at the rate of 8 pounds per 1,000 square feet (left) prevented the coming in of dandelions.

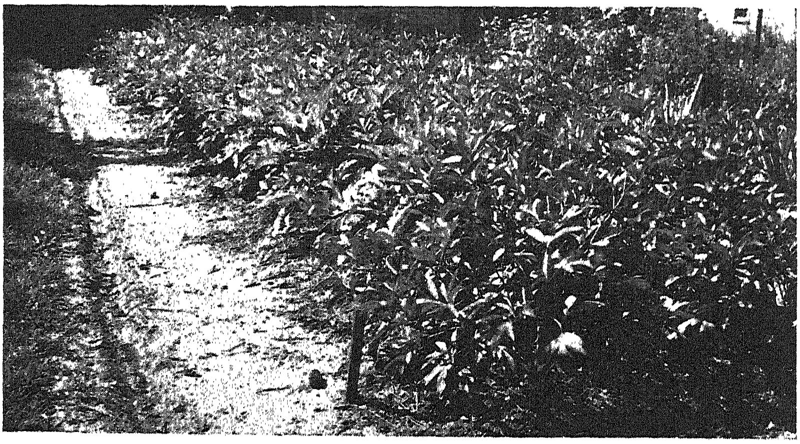

FIG. 4.—Sodium chlorate used to control weeds in a border without injury to adjoining flowers.

2. One pound of sodium chlorate in a gallon of water (12%) applied to 100 square feet is usually sufficient, but with unfavorable climatic and soil conditions, especially where sandstone comes close to the surface, the strength of the solution should be increased to 1½ pounds or even 2 pounds per gallon.
3. For safety in seeding the following spring, the applications should be made before the first of the year or about 3 months before it is expected to reseed.
4. By this procedure, it is possible to renovate an old lawn without spading or plowing up, but the plan is recommended only where there is not enough grass to make it worthwhile to save.

BORDER ROWS OF OAT PLATS AS AFFECTING YIELDS AND VARIABILITY[1]

C. K. McClelland[2]

In a previous article[3] it was shown that, though border rows produced 32% higher yield than interior rows (data from an 8-disc, 8-inch drill), the yield from all rows was only 8% greater than if calculated from interior rows. Furthermore, when the area of the narrow alley (width 8 inches net, 16 inches between grain rows) was included as a part of the plat, the yields calculated from all rows was 3.9% below that calculated from the interior rows.

In a continuation of these studies made in 1929, 1930 and 1931, the work was broadened to include two widths of alleys, *viz.*, 8 and 16 inches and varying widths of plats as made by varying numbers of rows of grain. The method of conducting the tests was to drill the grain crop solidly in the field as any farmer would drill it and then when the seedlings were emerging to take a hand or garden plow and destroy such rows as would give desired sizes of plats and widths of alleys. At harvest time rows 15 feet in length were harvested, these being replicated as shown in the various tables. The use of short lengths of rows permitted the use of the nursery thresher and restricted the demand upon labor during the rush period of harvesting.

Table 1 gives the summary of the tests made with Appler winter oats in 1928–29.

The gain of first border rows with the 8-inch alley ranges from 5.8 to 45.9%, averaging 24.9%. With the 16-inch alley the range is from 37.7 to 73.8%, averaging 52.5%. On second borders there is much less yet quite a noticeable effect, averaging 3.8% with 8-inch alleys and 6.9% with the wider alleys. The average yield from the second borders with the 8-inch alleys is not markedly different from

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[2] Assistant Agronomist.

[3] McClelland, C. K. The effect of narrow alleys on small grain yields. Jour. Amer. Soc. Agron., 21 : 524–532. 1929.

TABLE 1.—*Relative yields of inside and outside rows in different widths of plats and alleys, 1929, Appler winter oats.*

Plat width, number of drills 8 inches apart	Number of plats averaged	Yields per acre in bushels calculated from					Gain or loss of different yields as compared with yields of inner rows, %			
		1st border rows	2nd border rows	All inner rows	All rows of plat	All rows of plat plus alley	1st border rows	2nd border rows	All rows	All rows plus alley
With 8-inch Alley										
8	6	56.6	47.8	42.6	46.2	41.0	32.8	12.2	8.4	—3.8
9	6	49.3	45.5	46.6	47.2	42.4	5.8	—2.4	1.3	—9.0
10	6	57.2	46.3	46.9	48.8	44.4	22.0	—0.6	4.1	—5.3
11	6	58.9	47.8	47.6	49.6	45.4	23.7	0.4	4.2	—9.5
12	6	62.6	55.4	50.1	52.2	47.9	24.9	10.5	4.2	—4.4
14	4	57.2	47.2	47.9	49.1	45.9	19.4	—1.5	2.5	—4.2
16	6	75.3	55.6	51.6	54.8	51.6	45.9	7.8	6.2	0.0
Average gain or loss, %							24.9	3.8	4.4	—5.2
With 16-inch Alley										
8	4	62.8	38.9	41.4	46.8	37.5	51.7	—6.0	13.0	—9.4
9	4	62.6	42.2	40.0	45.1	36.8	56.5	5.5	12.7	—8.0
10	4	86.4	53.6	49.7	57.1	47.5	73.8	7.8	14.9	—4.4
11	4	73.1	47.0	49.7	53.9	45.6	47.1	—5.4	8.5	—8.2
12	4	82.3	61.9	54.4	58.9	50.4	51.3	13.8	8.3	—7.4
14	4	70.4	51.2	47.1	50.3	44.2	49.5	8.7	6.8	—6.2
16	4	61.0	54.8	44.3	46.6	41.4	37.7	23.7	5.2	—6.5
Average gain or loss, %							52.5	6.9	9.9	—7.1

the yield of all rows considered without the alley which was 4.4% higher than the yield from the interior rows.

When the area of the alley is included in the area of the plat, hnowever, the yields are reduced, showing that the border rows do not make full use of the alleys. The larger growth of clover in these alleys, as shown in the article previously mentioned, is explained by this failure of the border rows to make full use of the alley spaces. The reduction varies from 0 to 9.5%, averaging 5.2%, the figure for the 8-row plats (3.8%) agreeing closely with previous findings. With 16-inch alleys, as might be expected, there is more waste of space, the reductions varying from 4.4 to 9.4% and averaging 7.1% from the yields of the interior rows. There is no indication in this test, however, as to proper width of plat and alley to use to secure yields identical or closely identical with that obtained from the interior rows.

On account of winter killing the study with winter oats in 1929–30 was valueless; the first borders were injured the more severely, the second borders showing the greater border effect. Similar studies, however, were made with Fulghum spring oats in 1930 and again in 1931, and the results tabulated as in Table 1 for 1929. The results for the 3 years are summarized in Table 2.

TABLE 2.—*Summary of 3 years test on border effect on oat plats, 1929–31.*

Year	Number of plats	Gain or loss of different yields as compared with yields of inner rows, %			
		1st border rows	2nd border rows	All rows	All rows plus alley area
		8-inch Alley			
1929	40	24.9	3.8	4.4	— 5.2
1930	26	18.4	8.0	4.3	— 4.3
1931	38	34.1	2.3	6.9	— 2.1
Average		25.8	4.7	5.2	— 3.87
		16-inch Alley			
1929	28	52.5	6.9	9.9	— 7.1
1930	10	24.6	1.5	5.3	—12.7
1931	19	54.0	—5.2	8.3	— 7.8
Average		43.7	1.1	7.8	— 9.2

In 1930 the gain of the first border rows over inner rows averaged 18.4% with 8-inch alleys and 24.6% with 16-inch alleys; greater with the former but much less in the latter case as compared with the results with the winter oats as given in Table 1. The second borders averaged 8% gain with 8-inch alleys and only 1.5% with the wider alleys, reversing their rank of the preceding test. The gains of all rows were 4.3% and 5.3%, respectively, over that obtained from the interior rows. With the alley area included the average reductions become 4.3% and 12.7%, respectively, below the yield of the interior rows.

Some very erratic deviations occurred in the 1930 tests. The averages in some instances were considerably reduced. There was some indication that plats having 11 to 16 rows with 8-inch alleys will give the nearest approach to yields as obtained from the interior rows only. The use of wide alleys shows greater percentage reduction in yield than in the previous year's test with Appler oats.

The results of the 1931 test are more closely in agreement with the results of 1929. The average gains of the first border rows were 34.1% and 54%, respectively, with the narrow and wide alleys. The yields from all rows show gains of 6.9% and 8.3%, respectively. With the inclusion of the alley, the reductions became 2.1% and 7.8% below the yields obtained from interior rows. The least reductions are obtained with the 12- 14- and 16-row plats and 8-inch alleys, agreeing in this respect with the 1930 results. The 1929 and 1931 results lack the wide variability of those obtained in 1930.

Although plats of varying widths are included in the above table, there is a well defined difference due to the influence of alley width. Border effect on first borders increases from 25.8% with the narrow to 43.7% with the wide alley. The second borders show much less alley influence, the reduction with wide alleys being ascribed to the increased vigor and competition of the first borders. When "all rows" are considered, variation from normal yields as determined by inner rows is greater with the wider alleys whether or not the alley is included. Yields are about 5 to 8% too high without the alley area and 4 to 9% too low when the alley area is included as part of the plat. The larger figures obtain when the 16-inch alley is considered and show that the grain makes less efficient use of the wider alley.

VARIABILITY

The question has been raised as to whether or not the variability would be increased by the inclusion of the border rows, especially in variety tests. In Table 3, the coefficients of variation are given for the various rows and combinations of rows for the oat crops of 1929 and 1930 and also for the variety tests of winter and spring oats in 1926.

TABLE 3.—*Variability of results by inclusion of border rows.*

	Coefficients of variation, %					
	1st border	2nd border	1st and 2d borders	3d and 4th borders	All inner rows	Average of all rows
Winter oat varieties, 1926	30.0	36.3	24.3	22.4	27.2	33.7
Spring oat varieties, 1926	21.2	20.5	19.3	17.2	22.0	24.6
Appler winter oats 1929:						
8-inch alley	27.9	29.3	23.4	23.0	18.1	16.7
16-inch alley	32.3	33.3	25.3	26.2	20.3	19.3
Fulghum spring oats 1930:						
8-inch alley	25.5	27.6	24.3	21.7	19.0	21.3
16-inch alley	24.6	17.3	18.2	17.5	15.4	14.0

The table shows greater variability with winter oats than with spring oats, and also with 16-inch alleys than with 8-inch alleys. Greater variability is shown with winter oat varieties than with Appler, and when "all rows" are considered, the same is true with the spring oat varieties in comparison with Fulghum. Seasonal variation, however, might account for much of this, but unfortunately no comparison can be made with seasonal effect eliminated. With the 8-inch alley in 1930 the inclusion of borders also caused a slight increase in variability.

REDUCTION IN YIELD WITH ALLEY AREA INCLUDED

For convenience the percentage reduction in yields for all plat and alley widths are brought together in Table 4.

The data indicate a lowering of the reduction percentages with the increase in the width of the plats, whether with the wide or narrow alley, but that the use of the narrow alleys where borders are not removed gives results more nearly normal. In Table 5 an analysis of these results by Student's method is given.

Comparing the means of the replications in the various widths of plats by the method of Student and using 30:1 as indicative of varia-

TABLE 4.—*Percentage reductions in yield by inclusion of alley areas.*

No. of drill rows	Percentage reduction of yields when alley areas are included in plat areas			
	1929	1930	1931	Ave.
	With 8-inch Alley			
8...............	—3.8 (6)*	— 8.5 (4)	+ 4.3 (4)	— 2.7
9...............	—9.0 (6)	— 7.1 (6)	— 5.6 (8)	— 7.2
10...............	—5.3 (6)	— 7.8 (2)	— 5.8 (4)	— 6.3
11...............	—9.5 (6)	— 1.0 (2)	— 4.5 (8)	— 5.0
12...............	—4.4 (6)	— 2.3 (8)	— 2.9 (6)	— 3.2
14...............	—4.2 (4)	— 1.7 (2)	— 0.8 (2)	— 2.2
16...............	0.0 (6)	— 2.0 (2)	+ 0.5 (6)	— 0.5
Average........	—5.2	— 4.3	— 2.1	
	With 16-inch Alley			
8...............	—9.4 (4)	—15.1 (2)	—13.4 (4)	—12.6
9...............	—8.0 (4)	—11.0 (2)	——	——
10...............	—4.4 (4)	—19.0 (2)	— 7.7 (3)	—10.4
11...............	—8.2 (4)	— 7.8 (2)	——	——
12...............	—7.4 (4)	—10.6 (2)	— 9.3 (4)	— 9.1
14...............	—6.2 (4)	——	— 5.8 (2)	——
16...............	—5.5 (4)	——	— 2.9 (6)	——
Average........	—7.1	—12.7	— 7.8	

*Number of replications in parenthesis.

TABLE 5.—*Odds by Student's method that the given gains or losses are not due to chance variation.*

Year	Differences as compared with yields of inner rows			
	First border rows (gain)	Second border rows (gain)	All rows of plat (gain)	All rows plus alley area (loss)
	Narrow Alleys			
1929	369	11.2	999	2499
1930	285	216.0	908	7.72
1931	4999	4.48	332	11.2
	Wide Alleys			
1929	4999	16.00	4999	9999
1930	28.8	1.56	22.9	269
1931	4999	5.75*	1666	168

*These odds in reference to a lowered yield.

tions not due to chance, it is clearly shown that first borders are unreliable in that they give an exaggerated value to the yield. Only in one case of the six did the second borders show significant gains over the interior rows. Due to the influence of the first borders, the yields from all the rows show significant gain over yields determined from the inner rows. This is true only when the exact area covered is considered. The low odds of 22.9 naturally follow from the inclusion of first borders where low odds of 28.8 were found.

With the inclusion of the alley area there is a reduction in yield below that obtained from the inner rows, but the fourth column shows some inconsistency in the reduction. The reductions as given in Table 4 averaged —2.1, —4.3, —5.2, —7.1, —7.8, and —12.7%, the two smaller losses (8-inch alleys, 1930 and 1931) failing to show significance.

SUMMARY

It is clearly shown that the inclusion of border rows in plat yields when exact areas are considered gives an exaggerated yield, varying from about 4 to 8% from that obtained from interior rows, with higher percentages when wider alleys accompany narrow plats.

The yield of first borders showed increases varying from 18.4 to 54.0%, the larger increases being due to wider alleys. The yields of second borders showed variations from —5.2 to 8% and were significant in only one case, that with 8-inch alleys in 1930.

The inclusion of the alley area with the occupied area changes the yields as determined from all rows from an exaggerated yield into one usually significantly below that obtained from the interior rows.

Inclusion of border rows of variety tests of winter grain caused greater variability than in tests where but one variety was concerned. There was less difference with spring oats varieties.

The use of wide alleys caused greater variation in the first border rows and added to the inaccuracy of the results.

The data are of value as an indication of the accuracy of the work in cases where insufficient help is available to harvest border rows.

THE CALCIUM, PHOSPHORUS, AND NITROGEN CONTENT OF GRASSES AND LEGUMES AND THE RELATION OF THESE ELEMENTS IN THE PLANT[1]

HARLEY A. DANIEL[2]

Although a large amount of data have been published on the chemical composition of forage crops, only a few correlations between the different elements in the plants have been made. Greenhill and Page (6)[3] studied the relationship between the nitrogen and phosphorus content of pastures and found that phosphorus showed consistently a very highly significant positive correlation with the nitrogen content of the plants.

Cooper (2) studied the ash constituents of pasture grasses and found a negative correlation of —9.44 ± .08 between calcium and phosphorus, a positive correlation of .001 for calcium and nitrogen, and a positive correlation .84 ± .03 between phosphorus and nitrogen.

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[1] Contribution from the Department of Agronomy, Oklahoma A. & M. College, Stillwater, Okla. Received for publication October 9, 1933.

[2] Assistant Agronomist. The writer wishes to express his appreciation to Dr. H. J. Harper for suggestions and criticisms received in the preparation of this paper; to B. F. Kiltz and other members of the Agronomy Department for assisting in collecting the grass samples; and to H. I. Featherly for the identification of the native grasses.

[3] Figures in parenthesis refer to "Literature Cited," p. 503.

He also found that where liberal amounts of available phosphorus and nitrogen are present in the soil, a negative correlation may exist between the amounts of these elements in certain legume plants.

Parker and Truog (9) concluded from their compilation of analyses secured from different sources that a rather close relationship existed between the calcium and nitrogen content of plants, while potassium, phosphorus, and magnesium do not bear this close relationship. Hart, Guilbert, and Goss (7) studied the seasonal changes in the chemical composition of range forage and showed that the calcium-phosphorus ratio is narrow in the grass species and extremely wide in the alfilarias, while bur clover is intermediate in this respect. They also found that some species, particularly the alfilarias, show an increase in calcium consistent with a reduction in phosphorus content. Ferguson (5) and Cruickshank (3) have studied the seasonal variation in the mineral content of plants and found the calcium-phosphorus ratio to be quite variable, while in some samples the phosphorus content exceeded that of the calcium.

The chemical composition of fodders and grasses in India have been studied by Padmonabha and Kayasth (10) who reported that certain grasses belonging to the Andropogon genus were rather low in total phosphorus and high in total calcium. The phosphorus content of the plants which they analyzed varied from 0.055 to 0.205%, while the calcium varied from 0.314 and 0.814%. Forbes, Beegle, and Mensching (4) found that sorghum contained on the average 0.410% calcium and 0.160% phosphorus. Ames and Boltz (1) studied the composition of the alfalfa plant and found that it contained 1.507% calcium, 0.290% phosphorus, and 2.720% nitrogen. A compilation of data on alfalfa hay by Henry and Morrison (8) gives phosphorus 0.235% and nitrogen 2.380%. No data were given on the calcium content.

EXPERIMENTAL PROCEDURE

Composite samples of mature grass were collected during 1929 to 1933, inclusive, from virgin soils in 52 counties in Oklahoma. The legumes were collected from experimental plats located on the Oklahoma Experiment Station farm and from outfield stations. The samples used for analysis were taken about the time the plants were ready to cut for hay. Some of the samples were collected from fertilized plats, but the data are an average of all plants collected from both the fertilized and unfertilized areas. A total of 703 samples of forage were analyzed in connection with this study, which included 368 samples of grasses and 335 samples of legumes.

The plants were dried at 105° C to remove moisture and were analyzed for calcium, phosphorus, and nitrogen by official methods recommended by the Association of Official Agricultural Chemists.

RESULTS

CALCIUM, PHOSPHORUS, AND NITROGEN CONTENT OF GRASSES

The chemical composition of 23 species of grasses are given in Table 1. A considerable variation in the composition of the different samples of the same species occurred in some instances. This variation was evidently due to marked differences in the fertility of the

TABLE 1.—*The calcium, phosphorus, and nitrogen content of grasses and legumes and ratio between these elements in the plants.*

Series No.	Common name	Botanical name	Number of composite samples analyzed	Composition			Ratios		
				Ca. %	P. %	N. %	Ca:P	N:Ca	N:P
		Grasses							
1	Triple-awn grass	*Aristida oligantha*	5	0.189	0.059	0.605	3.20	3.20	10.25
2	Drop seed grass	*Sporobolus asper*	1	0.198	0.097	0.580	2.04	2.93	5.98
3	Little blue stem	*Andropogon scoparius*	43	0.269	0.072	0.614	3.76	2.28	8.59
4	Big blue stem	*Andropogon furcatus*	26	0.276	0.086	0.515	3.10	1.86	6.79
5	Big and little blue stem	*Andropogon furcatus and scoparius*	154	0.395	0.088	0.740	4.46	1.87	8.37
6	Broom sedge	*Andropogon virginicus*	3	0.240	0.084	0.610	2.85	2.54	7.26
7	Silver beard grass	*Andropogon torreanus*	2	0.328	0.100	0.718	2.90	2.19	6.35
8	Sorghum*	*Andropogon sorghum*	20	0.330	0.090	1.226	3.66	3.71	13.62
9	Indian grass	*Sorghastrum nutans*	6	0.291	0.085	0.827	3.52	2.84	10.09
10	Short grass	*Bouteloua* and *Buchloe*	25	0.358	0.107	0.934	3.42	2.33	8.82
11	Buffalo grass	*Buchloe dactyloides*	14	0.339	0.126	0.987	2.69	2.91	7.82
12	Grama grass	*Bouteloua gracilis*	8	0.314	0.108	0.933	3.14	2.97	9.34
13	Switch grass	*Panicum virgatum*	8	0.286	0.110	0.932	2.60	3.25	8.48
14	Crab grass	*Syntherisma sanguinalis*	5	0.359	0.190	1.460	1.83	4.06	7.45
15	Diffused crab grass	*Leptoloma cognatum*	2	0.454	0.127	0.950	3.57	2.09	7.51
16	Love grass	*Eragrostis curtipedicellata*	1	0.322	0.143	1.302	2.25	4.04	9.10
17	Salt grass	*Distichlis spicata*	1	0.318	0.129	0.952	2.46	3.00	7.22
18	Purple top	*Triodia flava*	1	0.260	0.123	1.150	2.11	4.43	9.36
19	Wild rye grass	*Elymus virginicus*	6	0.187	0.124	1.017	1.51	5.43	8.20
20	Giant reed grass	*Calamovilfa longifolia*	2	0.167	0.141	0.544	1.18	3.25	3.86
21	Dallis grass	*Paspalum dilatatum*	4	0.186	0.137	1.109	1.35	5.95	8.10
22	Rye*	*Secale cereale*	13	0.289	0.234	1.643	1.23	5.69	7.02
23	Redtop	*Agrostis alba*	3	0.376	0.203	1.047	1.85	2.78	5.16
24	Orchard grass	*Dactylis glomerata*	1	0.340	0.205	1.465	1.66	4.31	7.14
25	Bermuda grass	*Cynodon dactylon*	14	0.659	0.179	1.294	3.68	1.96	7.30
Average of all grasses			368	0.351	0.103	0.868	3.41	2.47	8.42

	Legumes								
1	Sweet clover†	*Melilotus alba*	13	0.809	0.082	1.548	9.86	1.91	18.88
2	Peanut vines	*Arachis hypogaea*	8	1.889	0.065	1.274	29.06	0.67	19.60
3	Alfalfa	*Medicago sativa*	52	1.642	0.153	2.215	10.73	1.35	14.44
4	Sweet clover‡	*Melilotus alba*	153	1.275	0.125	2.118	10.20	1.66	16.94
5	Cowpeas	*Vigna sinensis*	13	1.833	0.165	1.944	11.11	1.06	11.79
6	Soybeans.	*Soja max*	22	1.085	0.180	1.803	6.10	1.66	10.01
7	Velvet beans	*Stizolobium deeringianum*	8	1.671	0.161	2.433	10.38	1.47	15.21
8	Mung beans	*Phaseolus aureus*	6	1.521	0.120	1.274	12.67	0.83	10.60
9	Japanese clover	*Lespedeza striata*	2	1.040	0.168	1.964	6.19	1.89	11.70
10	Sweet clover§	*Melilotus alva*	7	1.785	0.315	4.088	5.66	2.29	12.98
11	Hairy vetch	*Vicia villosa*	27	1.305	0.315	3.059	4.15	2.34	9.65
12	Austrian winter peas	*Pisum arvense*	24	1.380	0.254	2.961	5.43	2.15	11.65
Average of all legumes....................................			335	1.373	0.180	2.283	7.64	1.71	12.70

*Cut before heads appeared.
†Cut in the fall of the first year's growth.
‡Mature, cut in full bloom stage at the end of the second year.
§Cut in April, growing on second year roots.

soil on which the different samples were grown. Where five or more samples of any species of grass were analyzed the data are considered as representative of the plants growing in this section of the country. It will be noted that a marked variation in composition exists between the different species of grasses. Triple-awn grass and drop seed grass were very low in minerals and nitrogen and are some of the first grasses to appear on eroded soil. Indian grass, blue stems, and the other Andropogons are very low in phosphorus, varying from 0.072 to 0.100%. Their calcium content, on the other hand, was medium to high, while their nitrogen content was low when compared with the other species of grasses. Sorghum was higher in total nitrogen than the other Andropogons; however, this crop is grown on cultivated soil and tillage, because of its effect on available plant food, may increase the total nitrogen in the plant.

Buffalo grass, grama grass, switch grass, crab grass, diffused crab grass, love grass, salt grass, and purple top have a medium to high calcium, phosphorus, and nitrogen content. The calcium content of these grasses varied from 0.260 to 0.454%, and the phosphorus content from 0.107 to 0.143%. The nitrogen content of these plants was nearly the same with the exceptions of crab grass, love grass, and purple top, which were high in nitrogen. Crab grass might be expected to contain a higher nitrogen content than native grasses since it was collected from cultivated fields. Only one sample each of love grass and purple top was analyzed. Wild rye, giant reed grass, and dallis grass were medium to high in phosphorus and low in calcium, while the nitrogen content was about the same as that of the other plants, except that the nitrogen in the giant reed grass was very low. Such a condition would be expected since this grass has a tall, coarse stem. The calcium content of these plants varied from 0.167 to 0.187%. Further studies are being made on dallis grass.

Rye, redtop, and orchard grass were high in phosphorus and nitrogen, while the calcium was about the same as that of the other plants. The phosphorus content of these plants varied from 0.203 to 0.234%, and the nitrogen from 1.047 to 1.643%. Bermuda grass was much higher in total calcium than any of the other 22 species studied. The high calcium and phosphorus content of this grass makes it desirable for pasture. The average calcium content of this plant was 0.659% and the phosphorus 0.179%. All of the mature grasses studied were low in calcium and nitrogen as compared with the legumes.

The 368 grass samples averaged 0.351% calcium, 0.103% phosphorus, and 0.868% nitrogen.

CALCIUM, PHOSPHORUS, AND NITROGEN CONTENT OF LEGUMES

The chemical composition of 10 species of legumes is also given in Table 1. These data are the averages of fertilized and unfertilized plants and consequently represent a wide variation in soil fertility. They indicate that there is a wide variation in the composition of legume plants. Peanut vines and sweet clover (cut in the fall of the first year) were very low in phosphorus. The phosphorus content of these plants varied from 0.065 to 0.082%, which is similar to the data compiled by Henry and Morrison (8) who found that peanut vines contained 0.099% phosphorus. The calcium content of peanut vines was high, while that of the sweet clover was low when compared with the other legume plants. The nitrogen content of sweet clover was high, while the nitrogen content of peanut vines was low.

Alfalfa, mature sweet clover, cowpeas, soybeans, velvet beans, mung beans, and Japanese clover were high in calcium and medium to high in phosphorus and nitrogen. The calcium content of these plants varied from 1.040 to 1.833%, while the phosphorus varied from 0.120 to 0.180%. The nitrogen content of the different legumes was quite variable, ranging from 1.274 to 2.433%. Mung beans contained the lowest amount of nitrogen, while velvet beans were the highest. Hairy vetch, Austrian winter peas, and sweet clover (cut in April of the second year) are plants which are high in calcium, phosphorus, and nitrogen. The calcium content of these plants ranged from 1.380 to 1.785%. The percentage of phosphorus and nitrogen is very high when compared with that of the other plants. The percentage of phosphorus ranged from 0.254 to 0.318, while the nitrogen varied from 2.961 to 4.088.

The 335 samples of legumes averaged 1.373% calcium, 0.180% phosphorus, and 2.283% nitrogen. The legumes contained 3.91 times as much calcium, 1.74 times as much phosphorus, and 2.64 times as much nitrogen as the grasses which were studied in this experiment.

Studies on the composition of the soil which was secured from each area where a plant was obtained indicate that the kind of plant is more important than either the soil or soil treatment in determining the amount of mineral which will be present in the forage, although soils very low in available plant food produce plants which contain smaller amounts of that element that similar plants grown on more fertile soil.

RELATION BETWEEN THE CALCIUM, PHOSPHORUS, AND NITROGEN CONTENT OF PLANTS

A study of the ratios between the nitrogen, phosphorus, and calcium content of the different plants indicates that there is quite a variation in different species of grasses and legumes. The calcium-phosphorus ratio varied from 1.18 to 29.06, the nitrogen-calcium ratio from 0.67 to 5.95, and the nitrogen-phosphorus ratio from 3.86 to 19.60. The peanut vines had the highest calcium-phosphorus and nitrogen-phosphorus ratios and the giant reed grass the lowest. Peanut vines also had the lowest nitrogen-calcium ratio and dallis grass the highest. The average ratio of these elements in the grasses studied were as follows: Calcium-phosphorus, 3.41; nitrogen-calcium 2.47; and nitrogen-phosphorus, 8.42. The average ratios for the legumes were calcium-phosphorus, 7.64; nitrogen-calcium, 1.71; and nitrogen-phosphorus, 12.70. It is quite evident that the legume hay contains a much larger amount of calcium and nitrogen in comparison with the phosphorus which is present in the forage than the grasses and that the nitrogen in the grasses is much higher in relation to the calcium than in the case of legumes. No close correlation between these elements occurs when all of the analyses are considered.

A poor correlation exists between the calcium and phosphorus content of the different grasses and a negative correlation between these elements in the mature legumes. Sweet clover cut at the end of the first year's growth and that cut in April of the second year are the only plants that do not show a negative correlation between calcium and phosphorus. Plants which are extremely low in phosphorus seem to be rather high in calcium and plants which are low in calcium are high in phosphorus.

The nitrogen and calcium content of plants was also studied, and the data indicate that there is a very poor correlation between these elements in plants.

The relation existing between the nitrogen and phosphorus content of these plants indicates that there is a closer relationship between these elements than there is between calcium and phosphorus or calcium and nitrogen. Sorghum and big blue stem are the only grasses in which the nitrogen and phosphorus were not closely related. Since sorghum is a cultivated plant and some of the samples were secured from fertilized plats, the nitrogen content of this plant should be higher than plants grown in uncultivated soil. Big blue stem is a tall, coarse native grass, and this would probably account for its low nitrogen content. Mung beans, cowpeas, and soybeans are the only legumes that do not show a close correlation between nitrogen and phosphorus, and these plants are also tall and have large woody stems.

SUMMARY

The chemical composition of 368 samples of grasses and 335 samples of legumes were studied. These samples were representative of 23 species of grasses and 10 different legumes. The grass samples averaged 0.351% calcium, 0.103% phosphorus, and 0.868% nitrogen, while the legumes averaged 1.373% calcium, 0.180% phosphorus, and 2.283% nitrogen. These data indicate that the legumes on the average contained 3.91 times as much calcium, 1.74 times as much phosphorus, and 2.64 times as much nitrogen as the grasses. It was found that the mineral content of plants which are low in calcium and phosphorus remains low when these plants are grown on fertile soil. Crops which are high in calcium and phosphorus always contain large amounts of these elements, even though they are produced on poor soil.

The relation existing between the calcium, phosphorus, and nitrogen within the plants was studied. The legumes have low nitrogen-calcium and high calcium-phosphorus and nitrogen-phosphorus ratios, while the grasses, on the other hand, have high nitrogen-phosphorus and low calcium-phosphorus and nitrogen-calcium ratios. A very poor correlation exists between the calcium and the phosphorus content of the grass, and these elements show a negative correlation in mature legumes. Plants extremely low in phosphorus were usually high in calcium, and *vice versa.* A poor correlation existed between nitrogen and calcium content of the plants, while the nitrogen and phosphorus in the plants were closely correlated.

LITERATURE CITED

1. AMES, J. W., and BOLTZ, G. E. Nitrogen and mineral content of the alfalfa plant. Ohio Agr. Exp. Sta. Bul. 247. 1912.
2. COOPER, H. P. Ash constituents of pasture grasses, their standard electrode potentials and ecological significance. Plant Phys., 2 : 193–214. 1930.
3. CRUICKSHANK, ETHEL M. IV. Report on the seasonal variations in the mineral content of pastures. Jour. Agr. Sci., 16 : 89–98. 1926.
4. FORBES, E. B., BEEGLE, F. M., and MENSCHING, J. E. Mineral and organic analysis of food. Ohio Agr. Exp. Sta. Bul. No. 255. 1913.
5. FERGUSON, W. S. III. The seasonal variation in the mineral content of pasture with particular reference to drought. Jour. Agr. Sci., 21 : 233–240. 1931.
6. GREENHILL, A. W., and PAGE, H. J. II. The mineral content of intensively treated pasture and a relationship between the nitrogen and phosphorus contents. Jour. Agr. Sci., 21 : 222–232. 1931.
7. HART, G. H., GUILBERT, H. R., and GOSS, H. Seasonal changes in the chemical composition of range forage and their relation to nutrition of animals. Calif. Agr. Exp. Sta. Bul. 543. 1932.
8. HENRY, W. A., and MORRISON, F. B. Feeds and Feeding. Ithaca, N. Y.: The Henry-Morrison Company. Ed. 19. 1928.
9. PARKER, F. W., and TRUOG, E. The relation between the calcium and the nitrogen content of plants and the function of calcium. Soil Science, 10 : 49–56. 1920.
10. PADMONABHA, AIYER, A. R., and KAYASTH, R. W. Mineral composition of the fodders of central Provinces and Berar and its bearing on animal nutrition. Agriculture and Livestock in India, I : 526–532. 1931.

INDUCING EARLY FRUITING IN WINTER WHEAT BY SEED ACTIVATION[1]

GEORGE L. PELTIER and T. A. KIESSELBACH[2]

Within recent years Lysenko's (2, 3)[3] "Iarovization" of cereal crops has stimulated considerable interest. Several papers confirming this principle with winter wheat have appeared within the past year in America (1, 4). Its possible use in a winter wheat breeding program by way of inducing early fruiting was of special local interest. In 1932 a preliminary study with two winter wheat varieties was made at the Nebraska Experiment Station and continued the next year. The effect of freezing slightly germinated seed also was studied.

METHODS AND EXPERIMENTAL RESULTS

Briefly, the following methods were employed. Seed wheat was soaked for 10 minutes in an alcoholic solution of mercuric chloride for the purpose of surface sterilization and then placed in enough water to cover the seed. After 24 hours the water was thoroughly drained and the seed allowed to stand at a temperature of approximately 65°F for a second day, or until the plumules had broken through the pericarps. The seed was then placed in a dark cold eastern Nebraska conditions. Sown at the normal date for seeding spring wheat, near the first of April, it regularly fails to head. On the other hand, Turkey winter wheat seed held in a germinated condition for periods of 30, 45, and 60 days at temperatures barely above freezing in the dark, came into head at nearly the same time as Ceres spring wheat when sown comparably in the field in the spring. In a parallel test, Early Blackhull winter wheat headed a week earlier than the spring variety. Similar germinated winter wheat seed held at 35°F for periods of 7 and 15 days failed to head. These results confirm those of other investigators (1, 2, 4).

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[2] Plant Pathologist and Agronomist, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 506.

Subjecting corresponding lots of germinated seed to freezing temperatures either before or after the storage period had no influence upon the tendency to head. This would seem to disprove an opinion common among growers that freezing of the germinated seed is necessary to cause winter wheat to head when it fails to come up or is not planted until spring.

The physiological processes involved in seed activation, which induce early fruiting in winter wheat, as herein described, have not been fully determined. It is evident, however, that a certain degree of "aging" is essential.

LITERATURE CITED

1. GFELLER, F., DERICK, R. A., and FRASER, J. G. G. Yarovization or vernalization of cereal crops. Sci. Agr., 13 : 728–729. 1933.
2. LYSENKO, T. D. A study of the effects of the thermic factor upon the duration of development stages of plants. Azerbaijan Plantbreeding Sta. Bul. 3 : 169. 1928. (English summary.)
3. ————————. On the problem of Iarovization of corn, millet, Sudan grass, sorghum, and soy bean. Odessa Ukrainskii Inst. Sel. Buil. Iarovizatii Nos. 2 and 3. 1932.
4. MCKINNEY, H. H., and SANDO, W. H. Earliness and seasonal growth habit in wheat. Jour. Her., 24 : 168–179. 1933.

LIME REQUIREMENTS OF ALFALFA ON WISCONSIN SOILS[1]

H. H. HULL[2]

As a general rule, the strongly acid soils of Wisconsin are not capable of producing a good crop of alfalfa without an application of lime, but instances have been noted where good yields were obtained and an application of ground limestone gave but little response. In fact, some strongly acid soils produce larger yields of alfalfa than many soils of a lesser degree of acidity. Of course there are many factors concerned, of which the availability of phosphorus is perhaps the most important, but it appears that an acid condition is more detrimental to the alfalfa crop on some soil types than on others.

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[2] Instructor in Soils. For the many suggestions and criticisms received in the course of this investigation, the writer is grateful to Professor A. R. Whitson, under whose general supervision the work was done.

Albrecht (1)[3] has shown that the presence of different amounts of calcium in soils of the same pH value greatly affected the growth of soybeans in pot cultures.

RELATION OF pH TO THE AVAILABILITY OF PHOSPHORUS

Plummer (5) has summarized investigations pertaining to the influence which calcium may have in making phosphorus available. He states that the relation of lime to the availability of phosphorus seems to indicate that lime applied to an acid soil previous to phosphate application prevents, in part, tying up of the phosphorus as the more unavailable iron and aluminum phosphates.

Whitson and Stoddard (7) and Stoddard (6), in early work at Wisconsin, found a universal lack of phosphorus in acid soils. They concluded that the available phosphorus in a soil is largely in the form of calcium phosphate; and that the reason acid soils are low in available phosphorus is that the phosphorus is largely in the form of iron and aluminum phosphates.

Chapman (3) states that in the breaking down of organic matter in acid soils it seems reasonable to believe that the liberated phosphorus becomes fixed as iron and aluminum phosphates, which may be unavailable. If a good supply of lime is present in the soil, the decomposition of the organic matter is hastened due to increased biological activity and the phosphorus is fixed to a large extent as calcium phosphate, which is more available than the iron and aluminum phosphates.

Studies made in Wisconsin of alfalfa fields in which the growth was very uneven showed in nearly all cases a higher pH value and a greater supply of available phosphorus in the better portions of the fields. From a number of available phosphorus and pH determinations made on unlimed soils, there are indications that a pH of 6.5 or above may be desirable for maintaining a good supply of available phosphorus. Out of 38 samples collected from alfalfa fields which had never been limed or fertilized, 20 showed a reaction below pH 6.5 and an average available phosphorus content of 22 pounds per acre. The remaining 18 soils had a reaction above pH 6.5 and an average available phosphorus content of 48 pounds per acre. These facts lead to the belief that acidity is an important factor in the availability of the soil phosphorus and in the growth of alfalfa.

RELATION OF EXCHANGE CALCIUM TO SOIL ACIDITY AND RESPONSE TO LIME

For this study, soil samples and yield data were secured from a series of plats laid out in the spring of 1929. These plats are located in 12 counties in southern Wisconsin and represent a variety of soil types, a description of which follows.

Knox silt loam is a light-colored forest soil produced by the weathering of limestone and a thin bed of loess overlying part of the limestone. The topography is rolling to rough and the drainage is well developed.

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[3] Numbers in parenthesis refer to "Literature Cited", p. 513.

Marshall silt loam is a dark-colored prairie soil occurring in the same region and arising from the same parent material as the Knox, though the loessial cover is a little thicker.

Miami silt loam is a light-colored forest soil occurring in the glaciated limestone region of southeastern Wisconsin. The topography is gently rolling to rolling and the soils are well drained.

Carrington silt loam is a dark-colored prairie soil occurring in the same region as the Miami. For the most part it is of the same parent material as the Miami, but some areas have a covering of from 2 to 4 feet of loess. The drainage and topography are similar to the Miami.

Baxter silt loam is a light-colored residual limestone soil. It is well drained and the topography is rolling to rough.

Each test field contains a series of 17 plats. The first 12 plats of each series were limed and the last 5 plats were left unlimed. The fertilizer treatments consisted of NPK, PK, and P on the limed plats and PK and P on the unlimed plats. Every third plat was left unfertilized. These plats were seeded to grain and alfalfa in the spring of 1929. The grain was harvested and yields obtained. In 1930, two crops of alfalfa were harvested, and in 1931, due to dry weather in the latter part of the season, only one crop was harvested on most of the fields. The green weight per acre was determined in the field for each plat and samples were brought to the laboratory for moisture determinations. The yields per acre were calculated on the air-dry basis.

Chemical methods.—For the determination of replaceable bases, a 20-gram sample of 40-mesh air-dry soil was placed in a percolator tube and leached slowly with 500 cc of neutral normal ammonium acetate solution. The leachate was then evaporated to dryness and calcium and magnesium determined volumetrically. Ammonium acetate has the advantage over ammonium chloride in that it all volatilizes upon evaporating to dryness and gives more complete replacement of all bases. For the determination of total base capacity, the soil in the percolator tube was leached with 500 cc of normal calcium acetate solution to saturate the exchange complex with calcium. The calcium was then replaced by a subsequent leaching with ammonium acetate after the soil had been washed free of bivalent ions. The replaced calcium calculated as milligram equivalents was taken as the total base exchange capacity of the soil. Available phosphorus was determined by the Truog laboratory method, and the degree of acidity and pH were determined by Truog's zinc sulfide test and soil reaction test, using triplex indicator, respectively.

Table 1 gives a list of these plats arranged in order of their response to lime. It is seen from this table that all soils with low exchange calcium have a low pH and that all soils with high pH have a high exchange calcium content. The reverse of these statements, however, does not hold.

There is a slight correlation between the amount of exchange calcium and response to lime. The first three soils gave the greatest response to lime and have the smallest amount of exchange calcium. The next three soils gave a medium response and have a somewhat

TABLE 1.—*Correlation of acidity and exchange calcium with response to lime on silt loam soils.*

Field No.	Soil type	3 crops alfalfa yield on limed plats, lbs. per acre	3 crops alfalfa yield on unlimed plats, lbs. per acre	Increase due to liming, lbs. per acre	Acidity		M.E. exchange calcium per 100 grams soil
					Degree	pH	
1	Knox	10,283	4,375	5,908	Slight+	5.5	8.95
2	Knox	8,041	3,537	4,504	Slight	5.5	7.79
3	Knox	7,265	4,220	3,045	Slight	5.8	8.97
4	Carrington	7,332	5,206	2,126	Medium	5.6	11.47
5	Carrington	9,781	7,080	1,701	Strong	5.4	9.11
6	Carrington	11,903	10,652	1,251	Strong	5.6	11.39
7	Miami	3,841	3,674	167	Very slight	6.9	11.58
8	Marshall	8,701	8,550	151	Slight+	6.0	15.81
9	Marshall	10,010	10,110	0	Slight	5.8	14.18
10	Miami	6,207	6,425	0	Medium	5.5	12.16
11	Baxter	7,051	8,039	0	Slight—	5.8	12.55
12	Miami	10,499	11,574	0	Very slight	6.8	10.06

larger amount of exchange calcium; although field 5 contains only a slightly greater amount than the first three soils. The last six soils are somewhat higher in their average content of exchange calcium than the first six soils which responded to lime, but when individual soils are compared it is seen that fields 7 and 12 are no higher in exchange calcium than fields 4, 5, and 6. These fields, however, have a reaction of pH 6.8 and 6.9 and on this basis would not be expected to respond to lime. Field 8 has a reaction of pH 6.0 which is fairly good for alfalfa growth. Field 9 is more acid than field 8, but did not respond to lime. A study of the subsoil of this field revealed that at a depth of 4 feet the reaction was less acid and that the fifth foot had a reaction of pH 6.4 and an available phosphorus supply of 360 pounds per acre. Field 10 becomes neutral at a depth of 20 inches and field 11 at a depth of 18 inches. The season of 1929 was very favorable for alfalfa seeding, and it appears that the alfalfa on these last three fields succeeded in establishing a root system which came in contact with soil of a favorable reaction.

RELATION OF AMOUNT OF EXCHANGEABLE BASES AND PERCENTAGE BASE SATURATION TO SOIL ACIDITY AND RESPONSE TO LIME

In working with Illinois soils, Bray and De Turk (2) found that at about 80% saturation of the base exchange capacity and with a pH value of 6.5 to 7.0, satisfactory conditions for sweet clover production may be expected.

Pierre (4), in a greenhouse test with 13 soils formed under different climatic conditions and of different degrees of weathering, found a rather good correlation to exist between the base saturation of acid soils and plant injury. He concludes that, "The percentage base saturation is believed to be a more important factor in determining the growth of plants in acid soils than is hydrogen-ion concentration, soluble aluminum, exchange calcium, or total acidity."

There appears to be such a correlation between the percentage base saturation and response to lime in Wisconsin soils. There is also a correlation between the percentage base saturation and acidity of the soil as determined by the Truog zinc sulfide method.

The amount of total bases in the soil, expressed as M. E. per 100 grams of soil, was taken as the sum of the total exchangeable calcium and magnesium. Exchange sodium was not determined and the amount of exchange potassium was so small in comparison to the amounts of calcium and magnesium that it was considered negligible in calculating the percentage base saturation.

Table 2 gives the results of these analyses when the percentage base saturation is compared with the acidity of the soils.

TABLE 2.—*Relation of the amount of exchangeable bases (calcium and magnesium) and the percentage base saturation to acidity on silt loam soils.*

Field No.	Soil type	Acidity		M.E. exchange Ca and Mg per 100 grams soil	M.E. total base capacity per 100 grams soil	Percentage base saturation with respect to Ca and Mg
		Degree	pH			
7	Miami	Very slight	6.9	17.08	16.28	104.9
12	Miami	Very slight	6.8	13.41	14.40	93.1
3	Knox	Slight	5.8	11.62	14.71	79.0
8	Marshall	Slight	6.0	20.91	27.29	76.2
11	Baxter	Slight —	5.8	19.54	25.94	75.3
2	Knox	Slight	5.5	9.99	14.02	71.2
9	Marshall	Slight +	5.8	20.33	29.10	70.0
1	Knox	Slight +	5.5	11.95	17.14	69.7
10	Miami	Medium	5.5	16.36	24.81	66.0
4	Carrington	Medium	5.6	16.07	26.16	61.4
6	Carrington	Strong	5.6	16.54	26.75	61.8
5	Carrington	Strong	5.4	13.11	23.10	56.7

The fields in Table 2 are arranged into groups according to their increasing acidity as determined by the Truog zinc sulfide method. It is seen that there is no correlation between the amount of exchangeable calcium and magnesium and the degree of acidity. The amounts vary from 9.99 to 20.91 M. E. per 100 grams of soil, and this large variation occurs within the slight acidity group.

When the percentage base saturation is compared to the degree of acidity, a general correlation exists. If these same fields are arranged in order of their response to lime and are compared with the percentage base saturation, a correlation appears to exist.

From the data in Table 3 it is seen that there is a general correlation between the amount of exchangeable bases and response to lime. The plats which show response are, on the average, lower in exchangeable bases than those which did not respond, but variations within each group are such that the total amount of exchangeable bases gives very little indication as to the response to lime.

TABLE 3.—*Relation of the amount of exchangeable bases (calcium and magnesium) and the percentage base saturation to response from lime on silt loam soils.*

Field No.	Soil type	3 crop response from lime, lbs. per acre	Acidity		M. E. exchange Ca and Mg per 100 grams soil	Percentage base saturation with respect to Ca and Mg
			Degree	pH		
1	Knox	5,908	Slight +	5.5	11.95	69.7
2	Knox	4,504	Slight	5.5	9.99	71.2
3	Knox	3,045	Slight	5.8	11.62	79.0
4	Carrington	2,126	Medium	5.6	16.07	61.4
5	Carrington	1,594	Strong	5.4	13.11	56.7
6	Carrington	1,251	Strong	5.6	16.54	61.8
7	Miami	0	Very slight	6.9	17.08	104.9
8	Marshall	0	Slight	6.0	20.91	76.2
9	Marshall	0	Slight +	5.8	20.33	70.0
10	Miami	0	Medium	5.5	16.36	66.0
11	Baxter	0	Slight —	5.8	19.54	75.3
12	Miami	0	Very slight	6.8	13.41	93.1

There is a correlation between the response from lime and percentage base saturation if fields 9, 10, and 11 are omitted, for reasons previously stated. The soils which responded varied from 56.7% to 79% base saturation, while those which did not respond varied from 76% to 104.9%.

Omitting fields 9, 10, and 11, all soils with a reaction below pH 6.0 responded to lime; however, the response on the light-colored soils was much greater than on the prairie soils.

Two soils which were only very slightly acid and did not respond to lime show a high saturation. Field 7 supposedly had never been limed previous to this experiment; however, there are bases present in a form other than exchangeable bases, as evidenced by the high saturation of this soil.

Taking the series of plats as a whole, with one or two exceptions, the greatest response to lime occurred with the first crop. There were 7 fields out of the 17 which would have been plowed up the first spring had the entire field at each location appeared no better than the unlimed portion. These same unlimed plats gave a little more growth the second year, but even then the crop was very poor. This brings out the importance of limestone application to prevent failures and poor stands of alfalfa.

INFLUENCE OF ADDITIONS OF GROUND LIMESTONE ON pH VALUE OF SOILS

In order to determine the effects of additions of ground limestone on the reaction of the soil, determinations were made on limed and unlimed plats from all available fields which showed a need of lime according to the Truog acidity test. The fields included both sandy and silt loam soils and are listed in Table 4.

The data in Table 4 show that the addition of ground limestone did not have the same effect on all soils in changing the reaction. In general, it appears that where the pH of the soil was changed appreciably by the addition of limestone, a good response in alfalfa growth was obtained. Field 5, which was strongly acid and in which the pH was changed considerably by applying lime, did not show the response that was expected. Fields 5 and 6 are both Carrington silt loam soils. They are strongly acid and responded only slightly to lime. The addition of limestone has raised the pH value of field 5 considerably but has had practically no effect on field 6, even though 4-ton applications were made.

TABLE 4.—*Influence of additions of ground limestone on the pH value of soils.*

Field No.	Soil type	Response to lime, lbs. per acre, total for 3 crops	Degree acidity before liming	pH		Tons ground limestone applied per acre
				Before liming	3 years after liming	
1	Knox silt loam	5,908	Slight +	5.5	6.2	3
2	Knox silt loam	4,505	Slight	5.5	6.5	2.5
13	Boone fine sandy loam	3,727	Slight	5.5	5.8	2
3	Knox silt loam	3,045	Slight	5.8	6.2	2
5	Carrington silt loam	1,701	Strong	5.4	6.0	4
14	Miami sandy loam	1,594	Slight —	5.8	6.6	2
6	Carrington silt loam	1,251	Strong	5.6	5.7	4
8	Marshall silt loam	0	Slight	6.0	6.2	3
9	Marshall silt loam	0	Slight +	5.6	5.8	3
10	Miami silt loam	0	Medium	5.5	5.7	3
11	Baxter silt loam	0	Slight —	5.8	6.2	2

Fields 5, 6, 8, and 9 are prairie soils which contain a good supply of organic matter. As the application of large amounts of limestone has had little effect in changing the reaction of these soils, it appears that they are very highly buffered. The soil of fields 8 and 9 is of the same genetic origin as that of fields 1, 2, and 3. The only difference in these soils as they stand today is the effect of the vegetation grown upon them since they were formed. These soils are both of loessial origin and occur in the same regions of the state. The only apparent difference in them is in their organic matter content. The presence of this organic matter has, of course, exerted its effect and caused a difference in the physical properties of these soils, but what is perhaps more interesting is its great buffer capacity, and, as will be noted by referring to Table 2, the presence of this organic matter has had the effect of greatly increasing the base exchange capacity of soils 8 and 9 over soils 1, 2, and 3. The percentage base saturation of these two soil types, however, is about the same.

SUMMARY

From a number of available phosphorus and pH determinations made on unlimed soils, there are indications that a pH of 6.5 or above may be important for a good supply of available phosphorus.

There was a slight correlation found between the amount of exchange calcium and response to lime.

A general correlation was found between the percentage base saturation and the acidity of the soil, and a correlation also existed between the percentage base saturation and response to lime. A reaction of pH 6.0 marked the line between response and no response; however, the response was much greater on the light-colored soils than on the dark-colored soils.

The greatest response of alfalfa to lime occurred on the first crop. After the plants became more deeply rooted, the unlimed plats made somewhat better growth.

Additions of ground limestone to different soils did not have the same effect on their reaction. The dark prairie soils appeared to be more highly buffered than the light-colored soils.

Studies of the subsoil from different fields brought out the fact that if lime and a good supply of available phosphorus are present within 5 feet of the surface, the needs of alfalfa may be satisfied, even though the surface horizon is deficient in these nutrients.

LITERATURE CITED

1. ALBRECHT, W. A. Inoculating of legumes as related to soil acidity. Jour. Amer. Soc. Agron., 25 : 512–522. 1933.
2. BRAY, R. H., and DETURK, E. E. Field method for lime requirement of soils. Soil Science, 32 : 329–341. 1931.
3. CHAPMAN, H. D. Methods for determining "available" soil calcium. Jour. Amer. Soc. Agron., 21 : 92–107. 1929.
4. PIERRE, W. H. Hydrogen-ion concentration, aluminum concentration in the soil solution, and percentage base saturation as factors affecting plant growth. Soil Science, 31 : 183–208. 1931.
5. PLUMMER, J. K. The effect of liming upon the availability of soil potassium, phosphorus, and sulphur. Jour. Amer. Soc. Agron., 13 : 162–170. 1921.
6. STODDARD, C. W. Phosphate availability in its relation to soil acidity. Wis. Agr. Exp. Sta. Res. Bul. 2. 1908.
7. WHITSON, A. R., and STODDARD, C. W. Availability of phosphorus in relation to soil acidity. Wis. Agr. Exp. Sta., 23d Ann. Rpt., 171–181. 1906.

DO SOIL ORGANISMS COMPETE FOR NUTRIENTS USEFUL TO CROPS?[1]

R. E. STEPHENSON[2]

Soil organisms are competitive in their effect in removing and utilizing the same nutrients which crops need. The competition for available nitrogen can be relatively easily demonstrated, in fact is a matter of practical experience. When straw or other low-nitrogen material is applied to the soil, there follows a period of nitrogen shortage for the crop. The soil organisms exhaust the supply of available nitrogen in decomposing carbonaceous materials of low-nitrogen content.

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[2] Associate Soil Scientist.

Though organisms use mineral nutrients, phosphorus, calcium, and potassium, a demonstration of harmfully competitive action is rather difficult to provide. Soils that support greatest biological activity are usually most productive, in spite of the nutrients rendered unavailable through fixation by organisms.

Plant materials are 40 to 50% carbon and usually 1 to 4% nitrogen. The complete mineralization of such materials results in abundant production of carbon dioxide and appreciable production of nitric acid. The carbonic acid has very little solvent effect measureable by water extracts. The amount of water in the soil under field conditions is too small to permit a very marked solvent action due to the carbon dioxide in solution. In the laboratory, using a large volume of water saturated with carbon dioxide, and a small volume of soil, the solvent effect of carbonic acid is easily demonstrated. Possibly also under field conditions, where plant roots constantly remove products of solution, there may occur a material solubility effect due to the carbon dioxide liberated by both soil organisms and the roots of growing plants. Nitric acid has a marked solvent effect. The same is true of sulfuric acid liberated through biological processes.

The nutrition of soil organisms involves the fixation of much larger proportions of nitrate than of the mineral nutrients. Possibly, therefore, there is an appreciable competition between crops and organisms for nitrogen, when little or none for mineral nutrients is detectable. The following data are pertinent to this question.

EFFECT OF ADDING CARBOHYDRATES TO SOILS

Soil samples were weighed into beakers and treated with organic materials, dextrose and starch, which stimulate organisms without supplying nitrogen or mineral matter. Sodium nitrate was added in some cases to provide available nitrogen in the form of a neutral salt. This should insure a good growth of organisms. The beakers were kept at 25% moisture and incubated at room temperature. If the soil organisms reduced the supply of soluble mineral nutrients appreciably, the effect should be detected in the analysis of the water-soluble extracts.

The case for calcium as shown by results in Table 1 is not very clear. If there is a solvent action of carbon dioxide freeing the calcium, the effect should be greatest after about 3 days, when the organisms are at the height of their activity and should diminish with time, as the number and activity of organisms diminish. Dextrose or starch used without other treatment appears to produce such an effect. The same result obtains when lime is used with the organics. Sodium nitrate without organics in every case increases the amount of soluble calcium probably by exchange reactions. When sodium nitrate is supplemented with organics, there is usually a falling off in soluble calcium at successive samplings.

Should the micro-organisms fix sufficient calcium, there would be a reduction of the soluble form at the third sampling. At that period there has been sufficient time for the calcium to become converted into organic form by the multiplying organisms. This result follows in most cases but not in all. The data are therefore inconclusive.

The case with potassium is a little more consistent. The soluble potassium of the original soil, as shown by Table 2, is very low. This perhaps makes small differences more easily measured. Where the decaying organics stimulate the activity of the soil organisms, there

TABLE 1.—*Water-soluble calcium in presence of decomposing dextrose and starch.**

Treatment	P.p.m. Ca in soil sampled after		
	3 days	10 days	21 days
Check	28	32	32
Dextrose, 10 tons	60	28	32
Starch, 10 tons	32	14	24
$NaNO_3$, 1800 lbs.	48	44	84
$NaNO_3$ plus starch	44	28	24
Lime, 5 tons	140	112	160
Lime 5 tons, plus dextrose	152	112	88
Lime 5 tons and starch	164	104	100
Lime 5 tons plus $NaNO_3$	164	140	224
Lime 5 tons plus $NaNO_3$ plus dextrose	124	72	88
Lime 5 tons plus $NaNO_3$ plus starch	148	92	84
Lime 20 tons	184	208	264
Lime 20 tons plus dextrose	192	160	152
Lime 20 tons plus starch	192	164	128
Lime 20 tons plus $NaNO_3$	184	244	344
Lime 20 tons plus $NaNO_3$ plus dextrose	156	132	200
Lime 20 tons plus $NaNO_3$ plus starch	176	148	124

*Aiken silty clay loam soil was used in the entire study. Lime throughout this paper stands for $CaCO_3$. Calcium was determined by the permanganate titration. All data reported represent duplicate studies. The rates of treatment were for 2,000,000 pounds of soil throughout this paper. All water extracts were 5 parts of water to 1 of soil.

TABLE 2.—*Water-soluble potassium in the presence of decomposing dextrose.**

Treatment	P.p.m. K in soil sampled after		
	3 days	10 days	21 days
Check	9.2	9.9	10.7
Dextrose, 10 tons	8.2	7.6	9.9
K_2SO_4, 800 lbs.	32.7	41.6	38.3
K_2SO_4 plus dextrose	28.4	31.9	32.7
K_2SO_4 plus dextrose plus 1,800 lbs. $NaNO_3$	24.5	13.5	14.9
$NaNO_3$ 1,800 lbs.	11.9	9.5	6.4
$NaNO_3$ plus dextrose	7.8	3.9	7.1
Superphosphate 1,200 lbs.	11.4	12.3	8.2
Superphosphate plus dextrose	8.2	9.2	8.5
Superphosphate plus $NaNO_3$ plus dextrose	7.4	6.0	4.5

*Potassium was precipitated as the potassium-cobaltinitrite and titrated with permanganate. Ordinary 16% superphosphate was used.

is somewhat consistently an apparent fixation of soluble potassium. Differences sometimes are not great however.

Phosphate is present in soluble form to the least extent of any of the common nutrients. The soil under study has a very high phosphate fixing power. Large amounts of soluble superphosphate are nearly completely removed from solution. The water-soluble phosphate, as shown in Table 3, indicates principally an increasing fixation with time. The acid-soluble indicates in most cases an increased fixation of phosphate, possibly by organisms, in the presence of decomposing dextrose. The greatest effect is with both dextrose and sodium nitrate which should stimulate greatest biological action.

TABLE 3.—*Water-soluble and acid-soluble phosphorus in the presence of decomposing dextrose.**

Treatment	P.p.m. water-soluble P as PO_4 in soil after			P.p.m. acid-soluble P as PO_4 in soil after		
	3 days	10 days	21 days	3 days	10 days	21 days
Check	0.06	0.06	0.08	18.6	18.3	18.3
Dextrose 10 tons	0.06	0.08	0.08	15.2	15.2	15.2
Superphosphate 1,200 lbs	0.46	0.12	0.08	60.9	45.7	36.6
Dextrose plus superphosphate	0.41	0.12	0.08	48.8	36.6	30.4
$NaNO_3$ 1,800 lbs	0.06	0.08	0.08	18.6	21.3	24.4
$NaNO_3$ plus dextrose	0.06	0.07	0.08	18.6	18.3	18.3
Superphosphate 1,800 lbs	0.50	0.23	0.23	91.4	111.8	52.0
Superphosphate 1,800 lbs. plus dextrose	0.50	0.38	0.21	91.4	91.4	52.0
Superphosphate 1,800 lbs. plus dextrose plus $NaNO_3$	0.46	0.23	0.23	97.5	86.3	40.5
Superphosphate 2,400 lbs	0.61	0.46	0.23	121.9	147.3	77.5
Superphosphate plus dextrose	0.57	0.61	0.23	102.1	133.1	68.6
Superphosphate plus dextrose plus $NaNO_3$	0.76	0.38	0.23	118.8	96.5	55.0

*Phosphate was determined by the blue colorimetric method in common use. Acid-soluble phosphate extracted with 0.002 N H_2SO_4 buffered to pH 4.0.

In general, reduced concentrations of soluble mineral nutrients where soil organisms have been stimulated to great activity by use of organic materials free from minerals is not easily determined. Neither dextrose nor starch contain nitrogen, sulfur, or chlorine to produce anions of strong solvent properties. There is, therefore, a minimum of solubility effects in the data presented.

EFFECT OF FARM-PRODUCED ORGANIC MATERIALS

The somewhat reduced amount of available mineral nutrients, calcium, potassium, and phosphate, when carbohydrates are added to the soil may be entirely changed when different types of organic matter are employed. In farm practice organic matter free of minerals and nitrogen is seldom used. Such organic materials as are commonly found supply more mineral matter than the organisms need for their nutrition.

Addition of a poor humus material, such as straw, results in the exhaustion of the supply of available nitrate in the soil as shown in Table 4. Since straw carries little nitrogen, its effect is much like that of a carbohydrate. It has very little effect in dissolving mineral nutrients. After 2 months the straw-treated soil contains only a fifth as much nitrate as the untreated and contains still less even after a year. When 1,200 pounds of sodium nitrate are used with the straw, the amount of nitrate in the soil after a year is no greater than where no treatment is given. Presumably the nitrate of the fertilizer has been nearly all fixed by the organisms which decomposed the straw.

TABLE 4.—*Water-soluble nitrate in presence of decomposing straw.*

Treatment	P.p.m. in NO_3 in soil after		
	2 months	6 months	12 months
Check	177	71	147
Straw 5 tons	35	44	124
Straw 5 tons plus 1,200 lbs. $NaNO_3$	310	195	147
$NaNO_3$ 1,200 lbs.	337	275	217

*Nitrate was determined by the phenol-disulfonic acid method.

Excellent humus materials, like stable manure and legume residues high in nitrogen and minerals, result in a considerable surplus of available mineral nutrients over the needs of soil organisms. This is shown by the data of Table 5. There is liberation of potassium from alfalfa and stable manure but none from straw by biological action.

TABLE 5.—*Water-soluble potassium in the presence of decomposing farm organics.*

Treatment	P.p.m. K in soil after		
	2 months	6 months	12 months
Check	21	19	18
Alfalfa 5 tons	31	26	27
Manure 5 tons	32	27	26
Straw 5 tons	22	17	19

The conclusion seems justified that any organic material which contains more than sufficient nitrogen for the soil organisms (2.0% or more of nitrogen) very probably will result in an increased supply of the available basic mineral nutrients for plant growth. Part of the basic nutrients are no doubt liberated from mineral matter of the soil by solution in nitric acid resulting from biological processes. Another portion of the mineral nutrients is liberated from the organic matter itself through decay.

Farm practice has demonstrated that competition even for nitrogen is a rather temporary effect. When low nitrogen organic matter is decomposed a large portion of the carbon is evolved as carbon dioxide. The protoplasm of the soil organisms is a high nitrogen compound. Dead organisms, therefore, form a very desirable type of organic matter readily decomposed. Thus the nitrogen and mineral nutrients fixed by organisms later become available to plants. The best time to use low-nitrogen organics on the soil is when there are no crops growing. The organisms then break down the poor humus material and convert part of it into a more desirable form (cells of organisms) during a time when competition cannot affect the crop. In fact, there are conditions under which bacterial fixation of nutrients may become a very effective means of preventing loss by leaching. A surplus of nitrate in an orchard soil in the fall may be partially saved from winter loss by a light mulch of straw, especially if the straw can be disked into the soil.

It is easily understood, therefore, why soils most active biologically are also most productive. Nutrients for plants must be in the form of nitrates, sulfates, phosphates, chlorides, and perhaps bicarbonates of calcium, magnesium, potassium, and other bases. Most of the anions are brought into action through the agency of organisms. Without the anions, the cations cannot become available. The small tax levied by the organisms in growing their own tissue is a minor outlay in exchange for the ready supply of soluble nitrients left in the soil under favorable conditions. The best types of organic matter are potentially rich in nutrient anions and cations. Thus, the superiority of legumes as humus materials. Important results of manuring and fertilizing include feeding soil organisms as well as feeding the crop. Only under unbalanced conditions do the organisms become harmfully competitive in their demands for nutrient materials.

CONCLUSIONS

1. Soil organisms utilize available mineral nutrients, but usually not to an extent to offer serious competition with crops.
2. Competition for mineral nutrients is much less easily demonstrated than is competition for available nitrogen.
3. The use of an organic, such as dextrose, which contains neither nitrogen nor minerals results in sufficient stimulation of biological activity to reduce somewhat the amount of water-soluble mineral nutrients found in the soil.
4. Decomposition of organics containing mineral nutrients and also fairly high in nitrogen, such as legume residues and stable manure, results in an increased supply of available minerals, particularly potassium, using water solubility as a measure of availability.
5. The beneficial effect of soil organisms in liberating plant food in the soil seems to overshadow possible harmful effects of competition.

THE EFFECT OF TYPE OF ENDOSPERM UPON CARBOHYDRATE DISTRIBUTION IN THE MATURE CORN PLANT[1]

W. B. KEMP and PAUL R. HENSON[2]

A sweet corn plant usually does not appear to produce as great a weight of grain as a dent corn plant of equal size and leaf area. McCluer (1)[3] and Kiesselbach and Cook (2) show that the individual kernel on a sweet corn ear has its weight increased about 20 to 30% by pollination with dent corn pollen. Unpublished studies by Rothgeb at this Station not only show that the individual kernel on a sweet corn ear has its weight increased 20 to 25% by pollination with dent corn pollen, but indicate also that the total weight of grain produced by the sweet corn plant is increased by such pollination.

It appeared as unlikely that the carbohydrate-assimilating power of the plant is increased by fertilization with dent corn pollen. Therefore, it seemed logical to assume that the change in the type of endosperm induced by such pollination affected the proportion of total carbohydrates which entered the kernels from the plant.

Studies were carried on during 1928 and 1929 in an effort to determine whether the distribution of carbohydrates in a corn plant can be varied by changing the type of endosperm in the kernels produced by that plant. The 1928 results were brought into question because plants were prostrated and partially uprooted by the heaviest rain in the history of the local weather station. However, the general findings in that year were corroborated by those of 1929. Analyses of dent corn plants were made also, but the results are not included because it seems desirable to confine all comparisons to plants of one genetic type.

The following procedure was carried out for the tests included in this report. Two sugar corn strains that resulted from many years of inbreeding were crossed to produce a vigorous progeny that would show a high degree of genetic uniformity. Seed resulting from the cross between these two inbred strains was planted in four rows 54 hills long. The plants in these rows were treated in one or another of three different ways. On some plants bags were put over the ear shoots to prevent pollination from any source. Other plants were pollinated with sugar corn pollen. Still others were pollinated with dent corn pollen. Repeated pollinations were made to insure well-filled ears.

It was desired to learn whether absence of grain on a plant results in the accumulation of excess sugars in the various plant parts; whether the presence of sugar corn kernels results in a partial drainage of these sugars into the kernels; and finally, whether the presence

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[1] Contribution from the Department of Agronomy, Maryland Agricultural Experiment Station, College Park, Md. Received for publication October 19, 1933.

[2] Associate Agronomist and Graduate Assistant, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 524.

of dent corn kernels results in practically complete drainage of sugars from all plant parts into the kernels.

Willaman, Burr, and Davison (3) present a bibliography of work prior to 1924 and show investigational evidence that sugars continue to accumulate in the sugar corn stalk after the ear is removed for canning.

The analytical studies reported here (Table 1) were made on the mature plants. Two plants from each series were selected for individual analyses, in order that it might be possible to know how much variation was present among plants of identical treatment. In selecting these plants for individual analyses, care was exercised to obtain well-developed plants of approximately equal total weight from all series. The remaining normal plants from each series were used in preparing composite samples for analyses. Separate analyses were determined on kernels, cobs, leaves and husks, and stalks. In all cases in preparing the plants each part was removed and weighed separately. The parts were ground in a Wiley mill fine enough to pass a 60-mesh sieve.

TABLE 1.—*Sugar corn plants classified to show the association between types of grain, percentage of grain, and percentage of starch and of sugar in grain and in plant.*

Plant No.	Weight in grams		Percentage of grain	Percentage starches and sugars		
	Total	Grain		Total	Grain	Plant
			No Grain			
Composite.....	134.14	0	0	13.08	0	13.08
Plant 1........	216.18	0	0	13.24	0	13.24
Plant 2........	195.66	0	0	14.00	0	14.00
			Sugar Grain			
Composite.....	252.40	96.16	38.1	23.53	52.25	5.85
Plant 1........	295.67	127.25	43.0	25.16	49.08	7.09
Plant 2........	318.39	149.09	46.8	28.35	54.71	5.14
			Dent Grain			
Composite.....	264.71	124.36	47.0	27.87	54.36	4.40
Plant 1........	235.38	123.89	52.6	33.87	62.36	2.21
Plant 2........	204.54	106.22	51.9	33.72	62.93	2.17

Table 1 shows the total weight of plant, weight of grain, percentage of grain, and percentage of starch and sugar in grain, plant, and total. Starch and sugar refers to total sugar, together with both soluble and insoluble starch-like material. Under plant number, "Composite" refers to the mixed sample from all normal plants, with the exception of two from each treatment. These two were analyzed separately and are designated as plants 1 and 2. The weight of the plants that were selected proved to be higher than the average in the sugar series and lower than average in the dent series. Typical plants on which no grain was permitted to develop were regularly lighter in weight than those on which either sugar or dent kernels developed. Hence the effort to select plants of about the same weight from all series for individual analyses resulted in selection of the heaviest plants that were produced among this type.

Figures in the last column of Table 1 show the marked tendency for total carbohydrates (starches and sugars) to accumulate in the plant when no grain is produced. These results agree with those by Sayre, Morris, and Richey (4) in analyses of field corn, with and without ears, grown in 1930. All green parts of these sugar corn plants without grain took on a reddish cast as sugars accumulated.

Further data in the same column of Table 1 show a tendency, less marked, for total carbohydrates to be drained more completely from the plant parts when dent kernels are produced than occurs when sugary kernels are borne on plants of the same genetic constitution.

Figures in column 5, showing percentage of grain, indicate that an increased proportion of the total weight is included in the grain when dent kernels are produced on these sugar corn plants. The individual plants regularly show larger percentages of grain than are shown by the composite samples. However, this is to be expected because particularly well-developed, well-eared plants were selected for individual analyses.

The percentage of starches and of sugars in the total, which includes both plant and grain, shows that the types producing the larger percentages of grain also produced the larger percentages of starches and sugars in the total. Thus the plants with dent kernels showed the highest percentages, those with sugar kernels showed percentages somewhat smaller, while the smallest percentages were shown by those plants which produced no grain. It may be observed further, that sugar kernels contained lower percentages of starches and sugars than were contained in dent kernels. Among the very interesting comparisons are those between percentage of starches and sugars in the kernels and in the plants which bore them, even among those of one kernel type. Within each group those plants with the lowest percentages in the kernels had the highest percentages remaining in the plant.

Table 2 shows in detail the parts of the plant where these carbohydrate residues were located and the forms in which they occurred. It may be observed that most of them were located in the stalky or pithy parts, while the forms in which they occurred were analyzed chiefly as sugars, with some soluble starch-like material.

In conclusion, it would appear that the final grain yield of the sugar corn plants used in this experiment is the resultant of the efficiency of the plant in two particulars, namely, the rapid and efficient elaboration of carbohydrates, and the rapid storage of these carbohydrates in the kernels in order that they may be drawn out of the plant and hence not interfere with continued elaboration. The most rapid and efficient storage in the kernels seems to take place when the material is stored in the form of insoluble starch.

To the extent that these findings hold generally, one may conclude that the production of sugar corn will always represent a less efficient plant process than is represented by the production of dent corn. Also, among sugar corns the efficiency should be increased when a large proportion of the starch-like material is stored in insoluble form. However, there might be conditions under which this increased efficiency will result in reduction of certain desirable qualities.

TABLE 2.—*Analyses of sugar corn plants classified to show the effect of type of grain upon carbohydrate accumulation in the various plant parts.*

	No grain			Sugar grain			Dent grain		
	Composite	Plant 1	Plant 2	Composite	Plant 1	Plant 2	Composite	Plant 1	Plant 2
Total:									
Weight, grams	134.14	216.18	195.66	252.40	295.67	318.39	264.71	235.38	204.54
Carbohydrates: Weight, grams	17.55	28.62	27.40	59.38	74.34	90.27	73.78	79.72	68.97
Per cent	13.08	13.24	14.00	23.53	25.16	28.35	27.87	33.87	33.72
Grain:									
Weight, grams	0	0	0	96.16	127.25	149.09	124.36	123.89	106.22
Sugar: reducing, %				0.66	0.87	0.83	0.05	0.08	0.00
Total, %				3.22	5.47	5.10	3.25	2.04	2.21
Starch-like material:									
Soluble, %				26.77	22.23	27.94	1.68	1.89	0.94
Insoluble, %				22.26	21.38	21.67	49.43	58.43	59.78
Carbohydrates, total %				52.25	49.08	54.71	54.36	62.36	62.93
Cobs:									
Weight, grams	10.40	14.74	11.03	26.37	33.34	36.18	21.16	28.25	20.22
Sugar: reducing, %	2.42	1.03	0.35	0.70	0.77	1.31	0.39	0.67	0.12
Total, %	3.12	1.10	0.41	0.77	0.88	1.56	0.62	0.82	0.24
Starch-like material:									
Soluble, %	3.12	4.58	4.38	1.35	0.97	0.62	1.14	1.50	1.34
Insoluble, %	0.06	0.28	0.00	0.09	1.18	0.57	0.71	0.39	0.84
Carbohydrates, total %	6.30	5.96	4.79	2.21	3.03	2.75	2.47	2.71	2.42

Leaves and husks:									
Weight, grams	67.96	89.65	83.66	82.92	73.96	69.34	66.00	55.42	41.45
Sugar: reducing, %	3.12	3.50	3.17	0.84	0.40	0.28	0.95	0.21	0.11
Total, %	4.42	5.37	4.40	1.40	0.40	0.34	1.05	0.24	0.18
Sratch-like material:									
Soluble, %	1.57	3.60	4.65	1.97	1.46	1.53	1.88	1.83	1.91
Insoluble, %	0.58	0.00	0.00	0.05	0.63	0.54	0.39	0.35	0.00
Carbohydrates, total %	6.57	8.97	9.05	3.42	2.49	2.41	3.32	2.42	2.09
Stalks:									
Weight, grams	55.78	111.79	100.97	49.65	61.12	63.78	48.19	27.82	36.65
Sugar: reducing, %	8.47	5.92	6.37	5.00	6.12	2.95	1.78	0.15	0.00
Total, %	17.39	9.92	12.90	8.08	11.14	7.14	2.52	0.16	0.23
Starch-like material:									
Soluble, %	4.77	7.70	6.21	3.45	3.03	2.03	4.68	1.09	1.78
Insoluble, %	0.12	0.00	0.00	0.00	0.70	0.29	0.00	0.00	0.08
Carbohydrates, total %	22.28	17.62	19.11	11.53	14.87	9.46	7.20	1.25	2.09
Total other than grain:									
Weight, grams	134.14	216.18	195.66	156.24	169.42	168.30	140.35	111.49	98.32
Carbohydrates: Weight, grams	17.55	28.62	27.40	9.14	11.94	8.70	6.18	2.46	2.13
Per cent	13.08	13.24	14.00	5.85	7.09	5.14	4.40	2.21	2.17

LITERATURE CITED

1. McCluer, G. W. Corn crossing. Ill. Agr. Exp. Sta. Bul. 21. 1892.
2. Kiesselbach, T. A., and Cook, G. C. The relative effects of foreign pollen upon the kernel weight of commercial varieties and selfed strains of corn. Jour. Amer. Soc. Agron., 16 : 30–36. 1924.
3. Willaman, J. J., Burr, G. O., and Davison, F. R. Cornstalk sirup investigations. Minn. Agr. Exp. Sta. Bul. 207. 1924.
4. Sayre, J. D., Morris, V. H., and Richey, F. D. The effect of preventing fruiting and of reducing the leaf area on the accumulation of sugars in the corn stem. Jour. Amer. Soc. Agron., 23 : 751–753. 1931.

A STATISTICAL ANALYSIS OF YIELD FACTORS IN SOYBEANS[1]

J. H. Weatherspoon and J. B. Wentz[2]

This paper is a report of a study of the relation between certain plant characters and yield in 237 strains of soybeans. First, a study was made of the extent of the differences between the 237 strains in the characters to be considered and then a statistical analysis was made of the relation of these characters to yield.

Although there have been extensive yield-analysis studies with the small grain crops, Woodworth[3] has done about the only work on analysis of yield in soybeans. He names number of nodes per plant, number of pods per node, number of seeds per pod, percentage of abortive seeds, and size of seed as important yield factors and emphasizes the importance of the use of these factors in selecting parents to be used in crosses. However, he found significant correlation between only two factors, percentage of abortive seeds and the weight of 100 seeds, and yield. Percentage of abortive seeds was negatively correlated with yield to the extent of —0.521, and the weight of 100 seeds was positively correlated with yield to the extent of 0.519. This study was made on 26 standard varieties. Under 25 degrees of freedom in tables given by Wallace and Snedecor[4] the least significant correlation is 0.381.

MATERIALS AND METHODS

The material used in this study was 237 soybean strains selected from the F_7 bulked progeny of a single F_3 plant arising from a cross of the two varieties Soysota and Ogemaw.[5]

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[1] Contribution from the Farm Crops and Soils Section, Iowa Agricultural Experiment Station, Ames, Iowa. Journal Paper No. J128. Received for publication October 23, 1933.

[2] Teaching Fellow and Associate Professor, respectively. The authors are indebted to Prof. G. W. Snedecor, statistician of the Iowa Agricultural Experiment Station, for suggestions relative to statistical methods and interpretations.

[3] Woodworth, C. M. Genetics and breeding in the improvement of the soybean. Ill. Agr. Exp. Sta. Bul. 384. 1932.

[4] Wallace, H. A., and Snedecor, G. W. Correlation and machine calculation. Iowa State Col. Off. Pub., 30: 5–69. 1931.

[5] The cross was made in the summer of 1922 by W. T. H. Ho, then a graduate student at Iowa State College and now engaged in teaching in China.

The F_1, F_2, and F_3 generations of the cross were grown by the pedigree method.[6] A large number of F_3 plants were selected and bulked progenies grown from each through the F_7 generation. The 237 strains used in this study were selections from one of these bulked progenies.

In the spring of 1932 a 27-inch row of each of these 237 strains, plus Manchu as a check, was planted in each of 10 blocks, making 10 27-inch rows of each strain. The strains were distributed at random within each block. In order to insure uniformity of stand the rows were thinned to 14 plants. It is with the yields and plant notes on this material that the present study deals.

Height of plant, number of nodes per plant, number of pods per plant, and number of pods per node were determined on two plants selected at random from each of the 10 replications.

The number of seeds per pod and the percentage of abortive seeds were determined from five pods selected at random from each of the selected plants.

The weight of 100 seeds was determined on each of the 10 replications at the time the seed was cleaned and yield weighed.

The variation for each character was analyzed into that due to block, that due to strain, and that remaining unexplained or experimental error. The strain and block variances of each character were then tested for significance.

All the possible simple correlations were calculated between means of blocks, between means of strains, and within the block-strain groups. From the two sets of simple correlation coefficients between strains and within the block-strain groups, corresponding sets of partial regression coefficients and corresponding multiple correlation coefficients were calculated.

RESULTS

As the 237 strains trace to a single F_3 plant, it was deemed advisable to find first if they actually differed in yield and in the characters to be correlated with yield. Accordingly, the method of analysis of variance was applied to the characters to be studied and the variation due to strain and to block tested for significance in each case.

STRAIN DIFFERENCES

Table 1 shows the analysis of variance of height of plant, number of nodes per plant, number of pods per plant, number of pods per node, number of seeds per pod, percentage of abortive seeds, size of seeds, and yield. In the table there are included for each character the degrees of freedom and the sum of the squares of the deviations from the mean. The significance of variations was then tested by comparing the z values with values in Fisher's[7] 0.05 and 0.01 tables of z appearing under the number of degrees of freedom involved in each z.

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[6] The first three generations were grown by Dr. Ralph T. Stewart, then a graduate student at Iowa State College and now associate professor of Agronomy at the Texas A. and M. College, College Station, Texas.

[7] FISHER, R. A. Statistical Methods for Research Workers. London: Oliver and Boyd, Ed. 3. 1930.

In Table 1, such mean squares as are significantly greater than the accompanying remainders are marked by asterisks. Single and double asterisks indicate that the corresponding values of probability are below the 0.05 point and 0.01 point, respectively. Mean squares with single asterisks are referred to as "significant," while those with double asterisks are designated "highly significant."

The mean squares indicate highly significant differences between the means of strains in all but one character. The difference between means of strains for percentage of abortive seeds was just significant. This indicates that the 237 strains really differed among themselves in all the characters studied.

The mean squares for differences between means of blocks indicate that the characters height of plant, number of pods per node, size of seeds, and yield are greatly influenced by soil differences. Number of nodes seems to be less influenced by soil differences, and the number of seeds per pod and percentage of abortive seeds show no significant differences due to soil.

In spite of the genetic relationship between the 237 strains of soybeans, they were widely enough different with respect to yield and plant characters to furnish suitable material for yield analysis studies. Some of the differences between strains were evident as they grew in the field and others were noticeable as notes were taken in the laboratory. The characters involved in the study no doubt are complex enough genetically so that there would be comparatively little homozygosity in the F_3 generation.

CHARACTERS CORRELATED WITH YIELD

It was demonstrated in the study of strain differences that the 237 strains under study differed significantly in the characters height of plant, number of nodes, number of pods, number of pods per node, number of seeds per pod, percentage of abortive seeds, seed size, and yield. In order to study the relation of these characters to yield, simple and multiple correlation coefficients and partial regression coefficients were calculated.

SIMPLE CORRELATIONS

Each factor was correlated with yield and with the other factors in all possible combinations. Table 2 shows these correlation coefficients between strain means.

Similar sets of correlation coefficients were calculated between replications and within the block-strain groups. A few significant correlations were found between blocks, but they were thought to be of little interest. A number of significant correlation coefficients were found within the block-strain groups which ran about parallel to those between strains but were much smaller. Since they give no information of interest other than that they are parallel to the between-strain correlations, they are not presented.

It can be seen from Table 2 that the four characters number of pods, number of nodes, number of pods per node, and height are significantly correlated with yield. Since pods per node is merely a ratio between two of the other factors, it may contribute little additional information.

TABLE 1.—*Analysis of variance of plant characters studied.*

	Degrees of freedom	Mean squares							
		Plant height	Nodes per plant	Pods per plant	Pods per node	Seeds per pod	Abrotive seeds	Size of seeds	Yield
Total	2,379	63.20	10.52	751.36	0.6467	0.0723	77.45	249.36	1,282.82
Between means of blocks	9	428.44**	12.33*	6,750.66**	8.1156**	0.1222	63.57	2,575.00**	11,314.00**
Between means of strains	237	358.68**	59.36**	1,999.61**	1.4355**	0.1302**	104.82*	1,143.56**	3,864.75**
Remainder	2,133	28.83	5.08	587.36	0.5275	0.0657	74.48	140.19	953.62

*One asterisk above a mean square indicates that the variation is significant, while two asterisks indicate that it is highly significant.

TABLE 2.—*Simple correlation coefficients between strains.*

Characters	Seed size	Percentage of abortive seeds	Seeds per pod	Pods	Nodes	Pods per node	Height
Yield	—0.1255	—0.1100	0.0869	0.5013**	0.4399**	0.2921**	0.4273**
Seed size		0.2691**	0.0838	—0.3048**	—0.5498**	0.0434	—0.4149**
Percentage of abortive seeds			0.1585*	—0.0683	—0.2488**	0.0969	—0.2198**
Seeds per pod				0.1222	0.0920	0.0780	—0.0580
Pods					0.5447**	0.7937**	0.3631**
Nodes						0.0686	0.8509**
Pods per node							—0.1734**

*A single asterisk indicates a significant correlation coefficient; two asterisks indicate high significance.

The fact that seed size is not correlated with yield can be accounted for by studying the simple correlations between the factors themselves. It will be noted that seed size is positively correlated with the percentage of abortive seeds and is negatively correlated with number of pods, number of nodes, and height, all of which were highly positively correlated with yield. That is, as the percentage of abortive seeds increases, the size of seed also tends to increase; while when number of pods, number of nodes, and height increase, the size of seed tends to decrease. This leads one to suspect that there is a physiological relationship involved, probably nutritional in nature, for with more aborted seeds and less vegetative development there are certainly more nutrients available for the development of the seeds present. There would be little chance then of ever producing a plant bearing large seeds, a low percentage of aborted seeds, a large number of pods and nodes, and great height. It seems probable that for this complex of factors to find expression it would have to be combined with the capacity to get more nutrients. A plant bearing all of these factors would certainly have to have the roots and the leaf area to support them.

It may be further noted in Table 2 that number of seeds per pod is significantly correlated with only one factor, percentage of abortive seeds, and that this correlation is barely significant. Since the percentage of abortive seeds is the ratio of number of abortive seeds to number of seeds per pod, one would expect here a negative spurious correlation. The fact that the correlation is significantly positive indicates a fairly high association between number of abortive seeds and number of seeds per pod.

MULTIPLE CORRELATION

In order to study the independent association of each factor with yield and the correlation of the whole complex of factors with yield, the partial regression coefficients and the multiple correlation coefficient were calculated. Since ratios are spuriously correlated with their numerators and denominators, two sets of partial regression coefficients were calculated; one excluding the two ratios seeds per pod and pods per node and one including them and excluding their denominators and numerators.

Table 3 shows the two sets of partial regression coefficients along with the simple correlation to which each corresponds. The first set of partial regression coefficients shows that height of plant and pods per node are the only factors significantly related to yield. Seeds per pod, percentage of abortive seeds, and seed size, as is shown by both their partial regression coefficients and their simple correlations with yield, are not significantly associated with yield.

In the second set, height and number of pods show highly significant partial regression coefficients and seed size shows one that is significant. Number of nodes shows a highly significant simple correlation with yield but a small non-significant partial regression coefficient. This indicates that the apparent relationship of number of nodes to yield is largely due to its association with height of plant.

TABLE 3.—*Partial regression coefficients for independent variables and yield.*

Set one			Set two		
Variable	Partial regression coefficients	Zero order coefficients	Variable	Partial regression coefficients	Zero order coefficients
Height........	0.5176**	0.4273**	Height.......	0.3145**	0.4273**
Pods per node..	0.3779**	0.2921**	Nodes........	0.0151	0.4399**
Seeds per pod..	0.0916	0.0869	Pods.........	0.4228**	0.5013
Abortive seeds.	—0.0700	—0.1100	Abortive seeds	—0.0501	—0.1100
Seed size.......	0.0840	—0.1255	Seed size......	0.1556*	—0.1255**

*One asterisk above a partial regression coefficient or a correlation coefficient indicates that it is significant; two asterisks indicate that it is highly significant.

It would seem, then, that the number of nodes a plant has makes little difference as regards yield so long as it has the necessary height.

It will be noted that seed size shows a significant partial regression coefficient in the second set but a non-significant one in the first set of partial regression coefficients. However, the difference is really very small and can probably either be accredited to chance or to the two ratios, pods per node and seeds per pod, present in the first set.

Two multiple correlation coefficients were next calculated. The correlation between yield and the complex of factors including height, pods per node, seeds per pod, percentage of abortive seeds, and seed size was 0.5805. The correlation between yield and the set of factors height, number of nodes, number of pods, percentage of abortive seeds, and seed size was 0.5822. There is, then, little difference in the efficiency of the two sets of factors in estimating yield. The second, however, has an advantage in that it involves the calculation of no ratios and shows the effect of each factor by itself instead that of a ratio. For this reason only the second set will be considered henceforth.

In order to see how much of the between-strain variation has been explained by the regression of yield on the factors height, number of pods, number of nodes, percentage of abortive seeds, and seed size, the percentage reduction in the between-strain variation by regression on the yield factors was calculated by means of the following formula:

$$\text{Per cent reduction in standard deviation} = 100\left[1 - \sqrt{\frac{n-1}{n-6}\,(1-R^2)}\right]$$

Substituting for n and R, percentage reduction in between-strain

$$\text{standard deviation} = 100\left[1 - \sqrt{\frac{238-1}{238-6}\,(1-0.5822^2)}\right] = 17\%.$$

This means that 17% of the standard deviations between strains has been explained by the regression of yield on the yield factors. It is then evident that the yield factors considered fall far short of accounting for all of the between-strain variance.

Since only 17% of the between-strain standard deviation has been explained by regression on the yield factors, the question now arises as to the relative amount each factor contributes toward the explanation of this 17% of the variation between strains. Table 4 shows the partial regression coefficients of each factor and the percentage each factor contributes toward this 17%.

TABLE 4.—*Percentage contributed by each yield factor.*

Yield factor	Partial regression coefficient	Percentage contributed
Height	0.3145	32.82
Number of nodes	0.0151	1.58
Number of pods	0.4228	44.13
Percentage of abortive seeds	—0.0501	5.23
Size of seed	0.1558	16.24

These data indicate that height of plant, number of pods, and seed size are the most important factors. Of these three factors, height of plant and number of pods per plant are outstanding in their relative importance.

SUMMARY

1. By analysis of variance it was demonstrated that the 237 strains of soybeans under study differed significantly in height of plant, number of nodes per plant, number of pods per node, number of seeds per pod, percentage of abortive seeds, weight of 100 seeds, and yield.
2. The characters height of plant, number of pods per node, size of seeds, and yield were greatly influenced by soil differences. Number of nodes per plant was less influenced by soil differences and the number of seeds per pod and percentage of abortive seeds were very little influenced by soil differences.
3. Significant simple correlations were found between yield and height of plant, number of nodes per plant, number of pods per plant, and number of pods per node.
4. Seed size was positively correlated with percentage of abortive seeds and negatively correlated with height of plant, number of nodes, number of pods per node, and number of pods. This indicates that there is probably a physiological relationship involved which would make combining large seed size with desirable expressions of these other characters very difficult.
5. A multiple correlation coefficient of 0.5822 was found between yield and its estimate from the complex of factors height, number of nodes, number of pods, percentage of abortive seeds, and the weight of 100 seeds.
6. Significant partial regression coefficients were given by height, pods, and weight of 100 seeds. The other factors gave very small partial regression coefficients indicating that they contribute very little information concerning yield not already given by the first mentioned factors.
7. Seventeen per cent of the variation in yield between strains was accounted for by its regression on the factors height of plant, number

of pods per plant, number of nodes per plant, percentage of abortive seeds, and seed size.

8. Height of plant and number of pods per plant were the most important characters in estimating yield.

ACCURACY OF THE PERCENTAGE OF LINT COTTON DETERMINED ON SMALL LABORATORY GINS[1]

J. T. VANTINE[2]

The yield of cotton in field experiments usually is reported in pounds of lint per acre, the yield being computed from the percentage of lint obtained on small laboratory gins. The accuracy of the percentage of lint is of considerable importance because it is a basic figure used in calculating yields. Since small plats are used in field experiments, errors would be magnified when the yield of lint is calculated to the acre basis.

The purpose of this study was to determine the amount of seed cotton required to obtain accurate results when cotton is ginned on an 8-saw and on a 20-saw laboratory gin at the main Experiment Station Farm, College Station, Texas.

Quinby and Stephens[3] made studies of methods of taking samples and the accuracy of the lint percentage determined from cotton ginned on small laboratory gins. They found that a 10-pound sample ginned on a 20-saw gin had a probable error of 0.18% lint and that a 200-gram sample ginned on an 8-saw gin had a probable error of 0.37%. The difference in the percentage of lint determined by the two sizes of samples was significant. They report that the difference in percentage of lint of cotton picked at different dates was significant and that it was necessary to get a representative sample from the total produce of the plat in order to secure a reliable percentage of lint. They found that the probable error of a single replicate was 0.28% lint which was almost the same as the probable error of a single sample drawn from a bulk lot of thoroughly mixed seed cotton. They concluded that one 10-pound sample from one plat of a replicated test is probably accurate enough to determine the percentage of lint where the soil is reasonably uniform.

MATERIALS AND METHODS

Twenty 10-pound samples were taken from a thoroughly mixed lot of Startex 582 cotton and ginned on a 20-saw gin. Fifty 200-gram samples and the same number of 50-gram samples were taken from the same lot of cotton and ginned on an 8-saw gin. The percentage of lint was calculated on the basis of clean seed cotton. The lint

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[1] Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Texas. Technical Paper No. 271. Received for publication October 31, 1933.

[2] Assistant in Agronomy.

[3] QUINBY, J. R., and STEPHENS, J. C. The accuracy of cotton lint percentage figures. Jour. Amer. Soc. Agron., 22 : 157 –163. 1930.

——————, ——————. Percentage of lint in distributed plats of cotton varieties. Jour. Amer. Soc. Agron., 23 : 67–69. 1931.

and the seed were weighed after ginning and the weight of the lint divided by the combined weight of the lint and the seed to obtain the percentage of lint. This method is used by the Texas Agricultural Experiment Station because it eliminates the effect of any difference in the amount of dirt and trash in the samples.

EXPERIMENTAL RESULTS

The means, standard deviations, probable errors of a single determination, and 3.2 times the probable error of a single determination are given in Table 1. The 10-pound sample was the most accurate with 0.37% lint for 3.2 times the probable error of a single determination.[4] This means that an error of as much as 3.7 pounds of lint per acre based on 1,000 pounds of seed cotton per acre would not be expected from the error of ginning when a 10-pound sample is used to determine the lint percentage. The 200-gram sample was not as accurate as the 10-pound sample. In a sample of this size 3.2 times the probable error of a single determination was 0.84% lint. This means that an error of as much as 8.4 pounds of lint per acre on the basis of 1,000 pounds of seed cotton per acre would not be expected when a 200-gram sample is used to determine the percentage of lint.

TABLE 1.—*Statistical constant for the size of sample ginned.*

	10-pound	200-gram	50-gram
Number of samples used	20	50	50
Mean (percentage of lint)	36.493±.026	35.701±.037	36.435±.056
Standard deviation	.171	.390	.579
Probable error of single determination	.116	.263	.391
3.2 times the probable error of a single determination	.370	.843	1.251

The 50-gram sample was not as accurate as the larger samples and generally a sample of this size would not be used on plats that are large enough for yields reported on the acre basis. This size of sample may be used in studying individual plants. If a representative sample could be obtained from a lot of cotton, the 50-gram sample is accurate enough for practical use. The factor for 3.2 times the probable error of a single determination of a 50-gram sample was 1.25% lint. On the basis of 1,000 pounds of seed cotton per acre, an error of as much as 12.5 pounds of lint per acre would not be expected from using one 50-gram sample to determine the percentage of lint.

The mean of the 50-gram and of the 10-pound samples was practically the same. The mean of the 200-gram samples was more than 0.7% lower than the other two means. Calculated on the basis of 1,000 pounds of seed cotton per acre, the percentage of lint from a 10-pound sample would show 7.91 ± .46 pounds more lint than a 200-

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[4] The statistical constants for the 10-pound samples and for the other sizes of samples are not exactly comparable, and those for the 10-pound samples may be considered somewhat exaggerated as they are based on 20 samples while those of the other sizes of samples are based on 50 samples.

gram sample, and the percentage of lint from a 50-gram sample would show 7.31 ± .66 pounds more lint per acre than the 200-gram sample.

Since the experimental error would probably be greater than 5% due to other uncontrolled factors, it is doubtful if a correction of 0.7%, the difference due to using different sizes of samples for ginning, is warranted.

SUMMARY AND CONCLUSIONS

Twenty 10-pound samples from a thoroughly mixed lot of seed cotton were ginned on a 20-saw gin and 50 200-gram samples and 50 50-gram samples of the same lot of seed cotton were ginned on an 8-saw gin to determine the accuracy of percentage of lint of samples ginned on laboratory gins. The error in percentage of lint of these samples was small. One representative sample carefully handled is sufficient to give a reliable determination of percentage of lint. The size of sample is not so important if a representative sample is used. There were significant differences between the different sizes of samples used, but these differences were small, and, in view of other experimental errors, the correction for the differences is probably not warranted.

A COMPARISON OF THE DRY MATTER CONTENT OF ANNUAL LESPEDEZAS, ALFALFA, AND SOYBEANS[1]

R. E. STITT[2]

The fact that annual lespedezas cure more rapidly than other legumes and that estimates of yields are usually less, rather than more, than the actual yields, indicates a relatively high dry-matter content at the time of harvest. It seemed desirable, therefore, to study the dry matter content of lespedeza, alfalfa, and soybeans when cut for hay and these data were obtained at Statesville, N. C., during the seasons of 1931 and 1932 from cultural and varietal test plats.

MATERIALS AND METHODS

Korean (*Lespedeza stipulacea*), Kobe, Common, and Tennessee No. 76 (*L. striata*) lespedezas were harvested for hay at intervals of about 2 weeks from the time the growth was tall enough to cut until seed had set. Plats 1/90 acre in area were cut with a mower and weighed. Two samples of approximately 5 pounds each were taken from each plat immediately after cutting for dry matter determination. The green samples were dried at a temperature somewhat in excess of 70°C until they had lost enough moisture to permit storing without danger of spoiling. Sub-samples taken later from the air-dry samples were dried in an electric oven to a constant weight at 100° C. The same technic was followed in determining the dry matter content of two samples from each of 22 plats of Utah Common alfalfa cut at one-tenth bloom stage and one sample from each of 28 plats of Laredo soybeans harvested when the pods were three-fourths filled.

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[1] Results of cooperative investigations conducted by the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; the North Carolina Agricultural Experiment Station, Raleigh, N. Car.; and the North Carolina Department of Agriculture, Statesville, N. Car. Received for publication November 4, 1933.

[2] Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

RESULTS AND DISCUSSION

The percentage of dry matter of the several varieties of lespedeza, Utah Common alfalfa, and Laredo soybeans are given in Table 1. During the 1931 season all lespedeza varieties showed a tendency to increase in percentage of dry matter as maturity advanced. The Korean variety normally matures about 30 days earlier than the Common, Tennessee No. 76, or Kobe, which accounts for the higher dry matter content of the Korean on similar dates. At any given stage of growth, however, the Korean variety appeared to contain a slightly lower percentage of dry matter than any of the other varieties. In 1931, Kobe slightly exceeded any of the other varieties in percentage of dry matter.

In 1932, drought was severe during the early stages of growth so that the dry matter content was high. All varieties contained approximately the same percentage of dry matter on August 29, 1932. During this dry period Korean lespedeza on bottom land, where the moisture supply was not limited, was lower in dry matter content than that grown on upland soil. The differences in dry matter content between Common and Tennessee No. 76 were insignificant during both seasons.

Under similar conditions lespedezas appear to have a higher dry matter content than soybeans or alfalfa, thus requiring a shorter period for curing. The stage of maximum growth of the annual lespedezas is coincident with full bloom and seed setting, at which time it is usually harvested for hay.

Alfalfa, on the other hand, is normally harvested at an earlier stage of maturity, when in one-tenth bloom. This explains to some extent the lower dry matter content of alfalfa as compared with the annual lespedezas when cut for hay, although at a similar stage of development the lespedezas still have an advantage in this respect. If alfalfa were allowed to reach the same stage of maturity at harvest as is customary with the annual lespedezas, the differences in dry matter content would not be so great, but the feeding value of the hay would be considerably less. That drought may result in an increase in the percentage of dry matter of alfalfa is shown by the cutting made June 29, 1931.

Soybeans are generally harvested when the pods are three-fourths filled. This stage of harvesting is similar to the stage when lespedeza is cut for hay and the results indicate that lespedeza is definitely higher in dry matter than soybeans.

TABLE 1.—*Comparison of the percentages of dry matter of green lespedeza, alfalfa, and soybeans, Statesville, North Carolina, 1931–1932.*

Variety and crop	Stage of growth	1931		1932	
		Date cut	Dry matter %	Date cut	Dry matter %
		Grown on Upland			
Common lespedeza.....	Vegetative	Aug. 28	28.0±1.03	Aug. 29	47.4±0.96
	¼ bloom	Sept. 11	27.5±0.38		
	Full bloom	Sept. 24	37.1±0.55	Sept. 30	36.4±0.30
	Dough	Oct. 8	41.5±0.79	Oct. 12	36.3±0.50
Tennessee 76 lespedeza	Vegetative	Aug. 28	27.6±0.76	Aug. 29	49.8±0.79
	¼ bloom	Sept. 11	28.3±0.49		
	Full bloom	Sept. 24	38.4±0.40	Sept. 30	36.9±0.30
	Dough	Oct. 8	42.8±0.86	Oct. 12	35.5±1.02
Kobe lespedeza........	Vegetative	Aug. 28	32.3±0.53		
	¼ bloom	Sept. 11	33.3±0.35		
	Full bloom	Sept. 24	43.0±0.31		
	Dough	Oct. 8	43.9±0.68		
Korean lespedeza......	Vegetative			Aug. 4	37.4±1.08
	¼ bloom			Aug. 16	38.2±1.40
	Full bloom	Aug. 28	36.7±1.54	Aug. 29	49.6±0.64
	Dough	Sept. 11	38.0±0.68		
Utah alfalfa 1/10 bloom	1st cutting	May 27	23.3±0.22	May 17	26.8±0.10
	2nd cutting	June 29	36.3±0.21	July 6	28.8±0.18
	3rd cutting	July 28	23.1±0.13	Aug. 22	26.8±0.19
	4th cutting	Sept. 9	25.0±0.13		
Laredo soybeans.......	Pods ¾ filled	Sept. 11	30.0±0.16	Aug. 29	28.2±0.34
		Grown on Bottom Land			
Korean lespedeza......	¼ bloom			Aug. 4	20.1±0.87
	½ bloom			Aug. 16	26.7±0.07
	Full bloom			Aug. 29	34.5±0.88

SUMMARY

The percentages of dry matter of the annual lespedezas at different stages of growth are compared. These data are compared with those of alfalfa when in one-tenth bloom and soybeans when the pods were three-fourths filled.

When similar growth stages are compared there appear to be distinct but slight differences in dry matter content between the varieties of annual lespedeza.

At the usual haying stage soybeans and alfalfa contain significantly lower dry matter content than annual lespedeza.

BOOK REVIEWS

COMMERCIAL FERTILIZERS, THEIR SOURCE AND USE

By Gilbert H. Collings. Philadelphia: P. Blakiston's Son & Co. Inc. XIV + 356 pages, illus. 1934. $3.25.

This is a compact, well-arranged, and carefully edited book, designed as a textbook on commercial fertilizers for agricultural colleges, and as a guide in the fertilizer industry. The emphasis is placed upon sources of raw materials, processes of manufacture, and characteristics and principal uses of the manufactured products.

Not only will this book be found useful by specialists in the fields of agronomy, soil science, and the fertilizer industry, but also by farmers, farm bureau managers, and others who have need for an up-to-date source of reliable information upon the newer forms of commercial fertilizer now on the market. (H. B. T.)

SOIL ANALYSIS: A HANDBOOK OF PHYSICAL AND CHEMICAL METHODS

By C. Harold Wright. London: Thomas Murby & Co. VIII+ 236 pages, illus. 1934. 12s. 6d.

The author states that the purpose in writing this volume was to provide both routine and research soil workers with a comprehensive laboratory manual of the best physical and chemical methods for examining soils. The assistance of other workers was freely used in selecting the methods described and the methods in all cases are presented in all their working details, with little of the theory underlying them.

Part I is concerned with physical methods, including sampling, determination of "single value" constants, mechanical analysis both by American and European methods, colloids, and hydrogen-ion methods. Part II deals with chemical methods for the common mineral constituents, while Part III describes methods for forms of soil nitrogen, carbon, availability of constituents, soil solutions, and base exchange. No less than 22 methods are described under base exchange. A valuable feature of the book is the citation of original sources of each method. No separate bibliography is given.

The book should be valuable to the soil laboratory worker as it brings together under one cover recognized soil methods which were previously scattered through a wide range of literature. (R. C. C)

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RAPID CHEMICAL METHOD FOR DETERMINING THE READILY AVAILABLE POTASH OF SOILS[1]

N. J. VOLK and E. TRUOG[2]

The need for a rapid chemical method for the determination of the adily available potash in soils led to this investigation of the relation etween exchangeable and readily available potash, and of procedures for the rapid determination of the exchangeable potash.

For the determination of available potash, Neubauer and Schneider used a seedling test and Mitscherlich (4) a pot test. References to e older literature are given by Wheeting (11), who found that leaching a soil with N ammonium chloride gave results agreeing better with e Neubauer method than did extraction with carbonic acid, water, r 1% citric acid, and concluded that the exchangeable potash is the adily available portion. Nostitz (7), also, found that plants are rgely dependent on the exchangeable potash, and that hydrochloric cid dissolves a greater quantity than this. Thornton (9) investigated the Neubauer test extensively, and concluded that a minimum of 10 mg of available potash per 100 grams of soil is adequate r general farm crops in Indiana. He kindly supplied us with 72 imples of his soils. Professor Mitscherlich of Germany also kindly ipplied us with 20 of his samples. A third set of samples was obtained from test plats in Wisconsin.

EXTRACTION OF READILY AVAILABLE POTASH

A comparative study was made of the advantages and disadvantages of various methods of extracting the exchangeable potash. able 1 gives a summary of this study. Normal ammonium acetate pH 6.8 proved more satisfactory than other extractants. It xtracts the potash effectively with a minimum of foreign substances d is easily removed by evaporation without crawling. A solution pH 6.8 is preferable to one of pH 7.0, because it extracts less ganic matter.

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[1] Contribution from the Department of Soils, University of Wisconsin, Madison, is. This investigation was supported in part by a fellowship grant from the gricultural and Scientific Bureau, N. V. Potash Export My., Inc., New York. blished with the permission of the Director of the Wisconsin Agricultural xperiment Station. Received for publication September 9, 1933.

[2] Fellow and Professor of Soils, respectively. The authors are indebted to rofessor A. E. Mitscherlich of the University of Königsberg, Germany, and to . F. Thornton of Purdue University for supplying most of the samples used in his study.

[3] Reference by numbers in parenthesis is to "Literature Cited," p. 546.

TABLE 1.—*The amounts of potash extracted from two soils by different solutions under various conditions of extraction.*

Kind of extracting solution	Method of extraction	Cc of extractant used per gram of soil	Mg of K_2O extracted from 100 grams of soil		Remarks
			Sandy loam	Fine sandy loam	
N CH_3COONH_4; pH 6.8	50, 10 cc leachings	25	4.50	12.60	Total exchange K_2O
0.001 *N* H_2SO_4	30 min. on shaker	10	5.10	15.70	More than exchange K_2O
N CH_3COONH_4; pH 5.0	30 min. on shaker	20	4.86	17.04	More than exchange K_2O
$(CH_3COO)_2Ca$; pH 7.0	30 min. on shaker	10	—	—	Ca interferes in determination
$(CH_3COO)_2Mg$; pH 7.0	30 min. on shaker	10	1.32	10.65	Viscous on evaporation
N CH_3COONH_4; pH 6.8	30 min. on shaker	10	3.50	11.95	Low result
N CH_3COONH_4; pH 6.8	30 min. on shaker	15	4.10	12.35	Satisfactory
N CH_3COONH_4; pH 6.8	30 min. on shaker	20	4.15	12.45	Satisfactory
2*N* CH_3COONH_4; pH 6.8	30 min. on shaker	10	3.72	12.30	Slightly low
2*N* CH_3COONH_4; pH 6.8	30 min. on shaker	15	3.98	12.45	Satisfactory
2*N* CH_3COONH_4; pH 6.8	30 min. on shaker	20	4.38	13.10	Satisfactory
N CH_3COONH_4; pH 6.8	5 shakings in 5 min.	15	4.00	12.30	Satisfactory
N CH_3COONH_4; pH 6.8	10 shakings in 10 min.	15	4.20	12.50	Satisfactory

An attempt was made to shorten the time required for extraction. Extraction with five intermittent shakings by hand (10 shakes each time, 50 shakes in all, taking about 5 minutes), using a soil-water ratio of 1 to 15, was just as effective as 30-minute shaking with the mechanical shaker. In further tests with nine soils, 89 to 100%, and on the average 96%, of the exchangeable potash, as measured by leaching, was removed by the 5-minute extraction. This method of extraction, being simple and sufficiently effective for most purposes, was therefore adopted. It, of course, also extracts all water-soluble potash. For certain exacting research needs, the leaching method should be used.

REAGENTS AND ANALYTICAL PROCEDURE

After extensive investigation, a method involving the following reagents and procedure was adopted.

REAGENTS

Normal ammonium acetate solution.—Mix the proper proportions of ammonium hydroxide, acetic acid, and water for a N solution of ammonium acetate, and adjust to pH 6.8, using brom thymol blue indicator.

Hydrogen peroxide solution.—Dilute 33 cc of 30% hydrogen peroxide to 100 cc, and just before using, add 2 cc of concentrated hydrochloric acid to each 100 cc.

Sodium hydroxide solution.—Dissolve 10 grams of potash-free caustic soda in 90 cc of water.

Dilute acetic acid.—Prepare approximately 0.15 N acetic acid by diluting 9 cc of 99% acetic acid to 1,000 cc with water.

Sodium cobalti-nitrite solution.—Dissolve 30 grams of $Na_3Co(NO_2)_6$ in 100 cc of water and filter through asbestos on a Gooch crucible. This solution is good for several months if kept below 10° C or in a tightly closed, glass-stoppered bottle so as to prevent escape of nitrous acid gas.

Dilute sulfuric acid.—Add 1 volume of concentrated sulfuric acid to 4 volumes of water.

Standard permanganate.—Prepare exactly 0.05 N potassium permanganate solution.

Standard oxalic acid.—Prepare exactly 0.05 N oxalic acid solution.

Asbestos.—Digest the asbestos in dilute nitric acid (1 part of acid to 10 parts of water) containing just sufficient permanganate to give a deep purple color. Add more permanganate if the color disappears and digest for at least 24 hours and until the permanganate color is permanent. Destroy any excess permanganate with oxalic acid, after which the asbestos should be pure white. Wash thoroughly on a Buechner funnel. Make a blank titration with standard permanganate on each purified lot of the asbestos, and if the titration figure is appreciable, subtract it in the regular determinations. Asbestos improves with use and may be used over and over again after purification.

ANALYTICAL PROCEDURE

Place 30 grams of 30-mesh, air-dry soil and 450 cc of N ammonium acetate solution in a 1-liter bottle. Shake by hand intermittently 5 times, giving the bottle 10 vigorous shakes each time, requiring 5 to 6 minutes for a set of 12 bottles. Filter immediately through a dry filter, pouring back the first 25 to 50 cc if cloudy, and evaporate a 375-cc aliquot of the filtrate, representing 25 grams of soil, to dryness on a hot plate at about 60° to 65° C. For greater speed, boil down gently to about 50 cc and then place *on a hot plate. Do not allow the solution to go to dryness at a boiling temperature, because the non-volatile acetates decompose at that temperature, forming carbon which resists oxidation later.*

On reaching dryness, wash down the sides of the beaker, starting close to the top, and evaporate to dryness again. This second evaporation usually leaves the residue fluffy, which aids in the destruction of the organic matter. It also gives mechanically-held ammonium acetate a chance to volatilize, thus lessening the quantity of sodium hydroxide needed later to expel the last traces of ammonia. (*Sodium in excess of 0.1 gram causes high results* (*10*).)

Add 5 cc of 10% hydrogen peroxide to destroy organic matter, and shake with a rotary motion so as to wet the sides of the beaker. Evaporate to dryness again. Repeat treatment, if necessary, to oxidize all organic matter. Wash down thoroughly the sides of the beaker, and add sufficient 10% sodium hydroxide to turn phenolphthalein distinctly red. If possible, avoid the use of over 1 cc of sodium hydroxide. Evaporate to dryness to drive off the last traces of ammonia, and, after cooling, add exactly 25 cc of approximately 0.15 N acetic acid. Police the sides and bottom of the beaker thoroughly, and then test one drop of the solution on a spot plate for ammonia with Nessler's reagent. If ammonia is present, rarely the case, add a few drops of 10% sodium hydroxide and evaporate to dryness, and then take up with 25 cc of 0.15 N acetic acid as before. After free of ammonia, filter the solution through a dry filter into a dry vessel and place a 20-cc aliquot, representing 20 grams of soil, in a beaker and set in a water bath at 10° C or below (10). To the cooled solution add, with vigorous stirring, 5 cc of the cooled (10° C or below) solution of $Na_3Co(NO_2)_6$. (*The writers (10) found that a greater concentration of* $Na_3Co(NO_2)_6$ *caused high results, and a lower concentration low results.*) Alcohol may be added to hasten precipitation, but it may cause too high results with large amounts, and a precipitate so fine with small amounts as to run through the filter pad, and hence its addition is not recommended.

After standing in the cold water bath or refrigerator 2 to 3 hours if the amount of potash is 1.0 mg or more, and over night if less, collect the precipitate on a *compact* asbestos pad in a Gooch crucible. A rubber stopper on the end of a stirring rod is conveniently used for compacting the asbestos, thus requiring less asbestos and making it possible to keep the precipitate on the surface of the pad where it may be seen. Rinse the beaker five times, pouring the rinsings into the Gooch so as also to wash the precipitate, and then wash the precipitate itself five additional times. *In washing, use water cooled to 10° C or lower.* Rinse off the outside of the crucible, remove the pad, and place both the pad and crucible into the original beaker and just cover with hot water. Add, first, a few cc of 0.05 N potassium permanganate from a burette, and then *immediately* 5 cc of dilute sulfuric acid. Stir the mixture vigorously to break up the asbestos, and continue to add permanganate until an excess is present. Place the beaker with contents over a low flame, and heat just to boiling. If the permanganate color begins to disappear, add more permanganate immediately. *An excess must always be present to prevent loss of nitrous acid.*

After removing from the flame, add from a burette 0.05 N oxalic acid, with stirring, until an excess of about 1 cc is present, and then allow the mixture to stand with frequent stirring for several minutes or until perfectly white. Titrate the excess of oxalic acid with 0.05 N permanganate. Each cc of 0.05 N permanganate consumed (consider only that added less that consumed by the oxalic acid and blank test) is equivalent to 0.0003259 gram of potassium or 0.0003926 gram of potash.

One can make 25 to 30 analyses per day with the method. In the remaining discussion, the method just described will be designated as the *Chemical Method.*

RESULTS BY CHEMICAL AND OTHER METHODS COMPARED

COMPARISON WITH THE NEUBAUER METHOD

The 72 samples of soil furnished by Thornton were analyzed by the chemical method, and the results, together with Thornton's Neubauer results, are given in Table 2, arranged in order of increasing amounts of available potash found by the Neubauer method. Thornton (9) concluded that 10 mg of potash per 100 grams of soil by the Neubauer method is the lowest amount that suffices for general farm crops in Indiana. Accordingly, in the first group of Table 2 are found the samples showing a deficiency, and in the second group those showing a sufficiency. Of the 25 samples in the first group, only two gave with the chemical method more than 10 mg of potash per 100 grams of soil, namely, No. 1631 with 11.1 mg and No. 1647 with 11.2 mg. Out of the 47 samples in the second group, only two gave under 10 mg with the chemical method, namely, No. 1637 with 9.5 and No. 1645 with 9.8. Thus, the two methods group the soils much alike as regards need for potash fertilization.

Influence of soluble salts.—In general, the differences in results by the two methods are greatest with the soils containing the higher amounts of available potash—soils suspected of being high in soluble salts. Accordingly, a 1 to 5 water extract of each soil was made and the soluble salts estimated by conductivity measurements. The results are given in Table 2 and indicate that below 1,000 p.p.m. of water-soluble salts the two methods agree reasonably well, but that above 1,000 p.p.m. the Neubauer method does not extract all of the exchangeable or soluble potash. Whether this is due to all of the soluble salts present or largely to active calcium, was next studied briefly.

Calcium antagonism to potash absorption.—Active calcium was determined by extracting 1 part of soil with 25 parts of N ammonium acetate solution. The results are given in Table 2. Markedly lower results with the Neubauer method are usually accompanied by high amounts of active calcium, and it appears that the readily soluble calcium may be the main factor interfering with the absorption of potash in the Neubauer method. This, in a sense, accords with Ehrenberg's (1) "Kalk-Kali-Gesetz". This factor has had little effect on the interpretation of the present results by the two methods, since the effect of the soluble calcium has not been sufficient to cause soils with high amounts of available potash to be placed in the wrong group as regards potash needs. This antagonism may be serious with low amounts of readily available potash, and may explain some of the pronounced responses to potash fertilization obtained on neutral and calcareous soils high in nitrates and hence soluble calcium salts. For this study, it would probably be better to determine the calcium soluble in water than that extracted with ammonium acetate solution.

Sears (8) found that the unproductivity of certain calcareous soils in northern Illinois is caused by a lack of potash and an over-abundance of nitrates. It is suggested that the injurious action of the high amounts of nitrates may be due to their bringing about a high

TABLE 2.—*A comparison of the amounts of potash extracted from soils by the Neubauer and chemical methods, also the amounts of water-soluble salts and calcium extracted with normal ammonium acetate solution; Neubauer results by Thornton.*

Thornton soil No.	Mg available K_2O per 100 grams soil		P.p.m. water-soluble salts	M.E. Ca extracted by N ammonium acetate solution	Thornton soil No.	Mg available K_2O per 100 grams soil		P.p.m. water-soluble salts	M.E. Ca extracted by N ammonium acetate solution
	Neubauer method	Chemical method				Neubauer method	Chemical method		
				Deficient by Neubauer Test					
1649	0.6	7.2	1,115	62.8	1738	5.4	6.9	173	4.7
430	0.6	3.7	—	—	1843	5.4	9.6	413	28.6
1800	1.2	2.9	165	3.2	1845	7.3	9.8	199	16.1
211	1.4	4.4	—	—	587	7.6	9.0	—	—
1799	1.8	5.0	70	3.5	1635	7.9	8.8	192	8.6
1801	1.8	2.1	111	4.5	619	8.1	7.1	—	—
433	1.8	3.3	—	—	1634	8.5	8.8	270	13.7
1646	3.6	8.9	413	45.2	1754	8.5	7.7	181	6.8
210	3.7	5.4	—	—	508	9.1	6.0	—	—
621	3.8	5.7	—	—	1638	9.1	8.6	235	12.8
557	4.0	5.0	—	—	1631	9.7	11.1	156	7.2
505	4.3	6.2	—	—	1647	9.7	11.2	413	34.8
1798	4.8	6.1	82	5.2					
				Not Deficient by Neubauer Test					
1637	10.9	9.5	221	13.1	661	22.2	15.5	—	—
1639	10.9	13.4	181	10.0	1585†	22.4	29.4	2,335	48.5
1577*	11.5	14.4	1,234	39.9	1737	23.6	19.8	273	8.7
1645	11.5	9.8	197	10.2	1756	24.2	19.9	306	4.3
1740	11.5	13.4	140	7.8	1576*	24.8	31.4	1,847	49.7
1587†	12.1	28.7	2,763	—	1588†	24.8	35.6	3,102	82.8
1643	12.7	10.5	224	10.7	1849	26.6	30.5	726	14.5
1644	12.7	12.8	154	13.0	1755	29.6	34.8	200	7.2
1648	13.3	13.4	616	36.9	1594	32.1	40.4	1,528	43.4
1650	13.3	14.3	586	57.5	1592†	32.7	50.4	3,272	57.7

1636	13.9	15.7	192	15.1	1753	33.3	29.1	418	5.0
1593†	14.5	25.9	3,046	56.8	1848	35.1	37.9	468	10.1
1640	15.1	12.8	275	14.2	1847	35.7	14.3	1,183	25.0
1641	16.9	10.0	200	11.2	1752	36.3	43.6	224	6.5
1583†	17.5	32.9	3,015	—	1846	36.3	27.4	464	14.3
1581*	18.2	18.5	702	30.8	1590†	36.9	59.7	2,835	58.0
1651	18.8	17.9	726	59.8	1586†	41.1	62.0	2,335	49.8
1642	19.4	14.1	419	11.0	1850	41.1	26.4	381	14.6
1739	20.0	23.2	275	7.1	1595	41.7	41.9	702	33.2
1589†	20.6	27.8	3,510	71.6	1591†	43.2	88.7	3,272	45.7
1578†	21.2	29.7	3,272	84.1	1580†	52.6	57.2	1,561	59.5
1579†	21.2	49.6	3,510	70.0	1582†	58.3	104.7	5,095	62.8
212	21.4	44.0	—	—	1584†	72.6	114.4	3,810	56.1
1844	21.8	16.9	346	8.1					

*Muck soil.
†Peat soil.

concentration of calcium nitrate in the soil solution (the nitrate being much more soluble than the carbonate or bicarbonate), which interferes with the absorption of potash by the plant, and thus accentuates the potash deficiency. This factor of antagonism is apparently involved in the data of Fonder (2), who found the contents of potassium and calcium in alfalfa to vary inversely.

COMPARISON WITH FIELD PLAT RESULTS

Soil samples from 13 alfalfa fields in Wisconsin under fertilizer test were analyzed and the results tabulated in Table 3 and compared with responses to potash fertilization. These results support placing the dividing line between soils that probably will respond and soils that probably will not at 10 mg per 100 grams of soil.

TABLE 3.—*The amounts of available potash by the chemical method in Wisconsin soils and increase per acre of alfalfa hay per cutting due to potash fertilization of these soils.*

Soil type	Available K_2O by chemical method, mgs.	Increase per acre due to potash fertilizer, lbs.
Boone sandy loam	6.1	621
Waukesha silt loam	6.3	543
Knox silt loam	7.0	193
Knox silt loam	8.6	122
Knox silt loam	10.0	121
Miami silt loam	11.2	0
Dodgeville silt loam	12.9	98
Carrington silt loam	13.2	0
Dodgeville silt loam	14.2	46
Dodgeville silt loam	14.7	65
Knox silt loam	16.2	0
Carrington silt loam	18.4	0
Carrington silt loam	26.0	0

COMPARISON WITH THE MITSCHERLICH METHOD

The 20 soil samples received from Mitscherlich of Germany, which he had tested with his pot culture method, were analyzed. Mitscherlich's results have been recalculated to mgs of potash per 100 grams of soil, and his minimum requirement for 98.6% maximum growth is approximately 10 mg of K_2O per 100 grams of soil. Results by both methods, given in Table 4, indicate that all of these soils are well supplied with available potash. The variations in amounts indicated by the two methods are to be expected when dealing with methods so different.

COMPARISON WITH THE *Aspergillus niger* METHOD

Reference to a recent paper by Mehlich, Truog, and Fred (3) shows that the chemical method correlates very well with the *Aspergillus niger* method.

TABLE 4.—*A comparison of the amounts of available potash in soils as determined by the Mitscherlich and chemical methods.*

Sample No.	Mgs. available K_2O per 100 grams soil		Sample No.	Mgs. available K_2O per 100 grams soil	
	Chemical method	Mitscherlich method		Chemical method	Mitscherlich method
1	19.1	19.6	11	13.1	31.4
2	40.2	25.5	12	29.2	24.5
3	31.4	98.2	13	29.4	27.5
4	30.0	25.5	14	19.4	33.4
5	27.8	21.6	15	10.9	29.5
6	21.5	23.6	16	38.8	28.0
7	19.5	29.5	17	38.2	19.2
8	28.0	19.6	18	21.6	19.6
9	30.6	25.5	19	46.1	24.1
10	26.0	31.4	20	45.2	18.2

INFLUENCE OF CROP, SUBSOIL, AND CLIMATE ON INTERPRETATION OF RESULTS BY CHEMICAL ANALYSIS

Although 10 mg of readily available potash per 100 grams of soil, or approximately 200 pounds per acre for the plowed layer of loam soils, has been set as the minimum amount which probably suffices, a number of factors may alter this amount. Approximately this amount is required in the northern states for the production of maximum yields of corn, small grains, and clover. The chemical method does not attack, appreciably, the difficultly available forms of potash like feldspars and micas. For alfalfa and clovers, having unusual feeding powers, these forms, when abundant in the soil and subsoil, may serve appreciably as a source of potash, but for corn, small grains, and truck crops, they have little practical importance.

For deep-rooted perennial crops, like alfalfa, the readily available potash of the subsoil to a depth of at least 5 feet is of considerable importance, and if it is quite high, 125 pounds per acre in the surface soil may suffice to produce fairly good crops. It is highly important, therefore, to test the subsoil to a considerable depth. Potatoes, tobacco, sugar beets, and other truck crops require more than 200 pounds per acre for maximum growth. Recently, Murphy (5) of Oklahoma reported results which accord rather well with ours regarding the level of available potash that is adequate.

Regions with a short and at times cold growing season require a higher level of available potash than regions like the southern states. A short growing season requires that growth be speeded up with an abundance of available plant nutrients. Regions of much cloudy weather apparently require a higher level of available potash for normal photosynthesis than regions of abundant sunshine like the Mississippi Valley.

In order that chemical soil analysis may develop into an accurate and valuable diagnostic procedure, it is necessary that soil chemists in different regions recognize the factors just mentioned in interpreting their results. Only in this way can they arrive at the correct conclusion regarding the reliability of a method.

SUMMARY

This study was undertaken for the purpose of developing a rapid chemical method for determining the potash needs of soils. The relation between readily available and exchangeable potash, and methods of extracting the latter, were studied. The results are summarized as follows:

1. Normal ammonium acetate of pH 6.8 was found to be more satisfactory as an extractant than other salt solutions and dilute acids, and the use of 15 parts of this extractant to 1 part of soil in 5 minutes of intermittent hand shaking resulted in an average extraction of 96% of the exchangeable potash. This method of extraction was adopted.
2. A detailed procedure for readily available potash, involving precipitation and titration as the cobalti-nitrite salt, is given. With this method, an analyst can make 25 to 30 determinations per day.
3. The results by the chemical method agreed with those by the Neubauer method on 72 samples in respect to positive or negative response to potash fertilization, and also correlated rather well with those by the Mitscherlich, the field plat, and the *Aspergillus niger* methods.
4. The influence of kind of crop, subsoil, and climate must be considered in arriving at the minimum level of readily available potash for any particular case.

LITERATURE CITED

1. EHRENBERG, P. Das Kalk-Kali-Gesetz. Landw. Jahrb., 54 : 1–159. 1919.
2. FONDER, JOHN F. Variations in potassium content of alfalfa due to stage of growth and soil type and the relationship of potassium and calcium in plants grown upon different soil types. Jour. Amer. Soc. Agron., 21 : 732–750. 1929.
3. MEHLICH, A., TRUOG, E., and FRED, E. B. The *Aspergillus niger* method of measuring available potassium in soil. Soil Science, 35 : 259–279. 1933.
4. MITSCHERLICH, E. A. Die Bestimmung des Düngerbedurfnisses des Bodens. Berlin: Paul Parey. 1930.
5. MURPHY, H. F. The replaceable potassium content compared with field response to potash fertilization of some Oklahoma soils. Jour. Amer. Soc. Agron., 26 : 34–37. 1934.
6. NEUBAUER, H., and SCHNEIDER, W. Die Nährstoffaufnahme der Keimpflanzen und ihre Anwendung auf die Bestimmung des Nährstoffgehalts der Böden. Zeitschr. f. Pflanzenern., u. Düng., A, 2 : 329–341. 1923.
7. NOSTITZ, A. Uber die Bedeutung des Austauschbasen Boden-kaliums für die Pflanzenernährung. Jour. f. Landw., 70 : 45–71. 1922.
8. SEARS, O. H. Relation of nitrates in soils to the response of crops to potash fertilization: I. Factors contributing to the unproductiveness of "alkali" soils in Illinois. Soil Science, 30 : 325–345. 1930.
9. THORNTON, S. F. Experiences with the Neubauer method for determining mineral nutrient deficiencies in soils. Jour. Amer. Soc. Agron., 23 : 195–208. 1931.
10. VOLK, N. J., and TRUOG, E. A study of factors involved and improvements in the determination of potassium as the cobalti-nitrite. In press in Ind. Eng. Chem., Anal. Ed. 1934.
11. WHEETING, L. C. A study of methods for the determination of the available potassium of soils. Soil Science 29 : 1–21. 1930.

A COMPARISON OF THE NEUBAUER, PLANT-SAP ANALYSIS, AND HOFFER STALK-TEST METHODS FOR DETERMINING THE NUTRIENT SUPPLY OF SOILS[1]

N. A. PETTINGER and S. F. THORNTON[2]

For the past several years the writers have been interested in the development and application of methods for determining the nutrient needs of soils. The senior author has been engaged in determining the value of the analysis of the expressed sap of corn plants as a guide to nutrient needs (3),[3] while the junior author has been interested in determining the reliability of the Neubauer method (5) and in developing simple chemical tests on plant material as indicators of fertilizer needs (6, 7). The former has found that the chemical composition of the sap of corn plants quite accurately reflects the supply of available nitrogen, phosphorus, and potassium in the soil, while the latter has found that the Neubauer procedure is an accurate and reliable method when the proper precautions are observed.

During the course of these investigations an opportunity presented itself for testing certain fertilizer plats by both the sap analysis and Neubauer methods, thereby making possible a determination of the degree of agreement between these two methods in estimating the available phosphorus and potassium requirements. Records also were available of the results obtained from the application of the Hoffer stalk test to the plants grown on the plats used in comparing the sap analysis and Neubauer methods; hence, a comparison has been possible of the available potassium requirements shown by three methods. It is the purpose of the present paper to present the nutrient-requirement data obtained by applying the Neubauer, sap-analysis, and Hoffer stalk-test methods to a series of plats which have received specified fertilizer treatments for more than 20 years, and to comment on the agreement shown by the results obtained by the different methods. The study covers the 5-year period of 1927–31, inclusive.

MATERIALS AND METHODS

The plats used in the studies reported here are known as the "Rotation with fertilizer" plats at the Virginia Agricultural Experiment Station, Blacksburg, Virginia. The experimental details concerning these plats have been given elsewhere (3), hence, only the more important features will be given here. Four series of fortieth-acre plats have carried in rotation the following crops since 1909: First year, corn; second year, wheat; third and fourth years, a hay mixture of mammoth clover and timothy. Stable manure and commercial fertilizers containing nitrogen, phosphorus, and potassium carriers have been applied alone and in the various combinations shown in Tables 1 to 5. All of the commercial fertilizers were applied annually at the following rates per acre: Ammonium sulfate, 200 pounds; dried blood, 308 pounds; rock phosphate, 219 pounds; superphosphate, 438 pounds; muriate of potash, 200 pounds. Stable manure was applied at the rate of 16 tons per acre once in 4 years just prior to plowing for corn, except on plat 12 where it was applied at the rate of 4 tons annually.

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[2] Associate Agronomist, Virginia Agricultural Experiment Station, and Assistant Chemist, Purdue University Agricultural Experiment Station, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 560.

The soil was classified in 1908 as a Hagerstown silt loam (8); however, changes in classification since this date indicate that the soil would now be classified as Frederick silt loam. Most of the plats have a reaction between pH 5.5 and pH 6.5. The soil samples for the Neubauer tests were collected in the usual composite manner to a depth of 6 inches. They were taken at the time the plants were pulled for sap extraction, which was usually the last week in August of each year.

The methods of analyzing the sap samples and of conducting the Neubauer tests have been given in previous publications by the writers (3, 5). The Hoffer stalk tests were made according to directions given by Hoffer (1).

PRESENTATION AND DISCUSSION OF RESULTS

COMPARISON OF METHODS FOR NITRATE TESTS

Since the Neubauer procedure does not include a test for available nitrogen, the data reported under this heading deal only with the sap-analysis and Hoffer stalk-test methods. The stalk-test method was used throughout the 4-year period of 1927–30, inclusive, while sap analyses were made for 1929–31, inclusive. The two methods were used concurrently in only 2 of the 5 years, namely, in 1929 and 1930. However, the data for the other years are reported also in order to supplement the direct comparisons of 1929 and 1930 and to indicate the performance of the various plats over a longer period of time than is given by the direct comparisons of these two years. The data are given in Table 1.

The data appear to be rather conflicting so far as any relationship between the Hoffer and sap-analysis methods is concerned. In some comparisons high stalk-test values are accompanied by low nitrate concentrations in the sap, while in other comparisons they are accompanied by high nitrate concentrations. Conversely, low stalk-test values are accompanied in some cases by low nitrate concentrations in the sap and by high concentrations in others. Thus, in 1929, eight plats gave stalk-test values of 5.0, the nitrate concentrations in the sap for the same plats ranging from 200 to 1,110. In 1929, plat $2X_2$ gave a stalk-test value of 1.0 and was accompanied by 149 p.p.m. of nitrate nitrogen in the sap. On plat $9X_2$ in 1930 the same stalk-test value was accompanied by 374 p.p.m. of nitrate nitrogen. Plat $3X_2$ gave the highest possible stalk-test value of 5.0 in 1929 and 200 p.p.m. of nitrate nitrogen in the plant sap; yet in the following year, the stalk-test value dropped to 3.8, while the nitrate concentration increased to 300 p.p.m. And finally, Table 1 shows stalk-test values of 3.5 and 3.3 accompanied by nitrate concentrations of 92 and 714 p.p.m., respectively.

However, the correlation between the two methods is not as negative as these comparisons indicate. In the first place, it is significant that the stalk-test values and the nitrate concentrations in the sap were both much higher in 1929 than in 1930. In 1929, only two plats gave stalk-test values of less than 3.5, while in 1930 there were seven such values. Similarly, in 1929, six plats gave sap values of less than 300 p.p.m. of nitrate nitrogen, while in 1930 nine plats showed nitrate concentrations below 300 p.p.m. The average stalk-test values of 4.4 and 2.7 for all plats in 1929 and 1930, respectively, and the average nitrate concentrations of 471 and 240 p.p.m. for the same years also emphasize the correlation between the two methods in showing the different nitrate levels in the two years where direct comparisons are possible. Secondly, a close study of the data in Table 1 shows that although there are a number of exceptions, the majority of the low stalk-test values are accompanied by low nitrate concentrations in the sap and the high stalk-test values by large quantities of reserve nitrates in the sap. That the two methods show a fair degree of positive correlation is indicated by the following averages for different intensities of nitrate accumulation:

Year	Nitrate nitrogen in sap, p. p. m.	Stalk-test values
1929	0 — 100	——
	100 — 300	3.93
	300 +	4.75
1930	0 — 100	1.45
	100 — 300	2.48
	300 +	3.84

The positive correlation between the sap-analysis and stalk-test methods is well maintained by the average data for all of the years in which the two methods have been used. It may be noted from Table 2 that in most cases the low stalk-test values are accompanied by low nitrate-nitrogen concentrations in the expressed sap, and that intermediate and high stalk-test values are accompanied by intermediate and high nitrate concentrations, respectively, in the sap of the plant. The strength of this relationship in the data in Table 2 is shown by the correlation coefficient +0.77 ± 0.076, which is considered to be very good in view of the more or less qualitative nature of the stalk-test method.

Table 2 also shows the extent to which the stalk-test values and the nitrate-nitrogen concentrations from the various plats fall within the limits of the more or less standardized values for different nitrate levels as given in published accounts of the two methods (1, 3). In describing the stalk-test method, Hoffer (1) has used alphabetical designations to refer to different nitrate levels, but in the present paper these terms have been converted into numerical values. These

TABLE 1.—*Nitrate tests by the sap-analysis and Hoffer stalk-test methods on plats receiving different fertilizer treatments.*

Plat No.	Fertilizer treatment*	Nitrates by Hoffer stalk test†		1929		1930		Nitrate nitrogen in sap, 1931, p.p.m.
		1927	1928	Nitrates by Hoffer stalk test	Nitrate nitrogen in sap, p.p.m.	Nitrates by Hoffer stalk test	Nitrate nitrogen in sap, p.p.m.	
$2X_2$	Ps	2.7	3.4	1.0	149	0.0	110	167
$3X_2$	N + Ps + K	5.0	2.4	5.0	200	3.8	300	125
$4X_1$	Check			4.8	165	3.5	92	204
$4X_2$	N(ams) + Pr	3.0	2.6	4.5	220	.8	56	176
$5X_2$	Ps + K	.7	.0	3.5	250	2.5	260	84
$6X_2$	K	5.0	1.8	5.0	370	3.5	120	500
$7X_2$	N + K	5.0	3.0	5.0	714	4.8	350	1,000
$8X_2$	N + Ps	3.7	4.2	5.0	322	1.5	72	286
$9X_2$	N	4.0	4.6	4.8	148	1.0	374	120
$10X_2$	M		5.0	5.0	1,000	4.8	150	856
$11X_1$	Check			3.3	714	.0	32	133
$11X_2$	M + Pr	5.0	3.4	5.0	312	4.3	460	750
$12X_2$	M	5.0	3.8	5.0	768	4.3	600	750
$13X_2$	M + Ps		3.8	5.0	1,110	4.8	400	910
$14X_2$	Pr	4.7	3.4	4.5	626	.3	230	240
	Averages			4.4	471	2.7	240	

*Check, no treatment since 1909; N, nitrogen from dried blood; N(ams), nitrogen from sulfate of ammonia; M, stable manure; Pr, rock phosphate; Ps, superphosphate; K, muriate of potash.

†Stalk tests made by W. P. Allyn in 1927, 1928, and 1929.

TABLE 2.—*Different nitrate levels as shown by the stalk-test and sap-analysis values and their correlation with nitrogen fertilization.*

Fertilizer treatment*	Descriptions of nitrate levels	Stalk-test data		Sap-analysis data		Average yield of grain per acre 1927–31, bu.
		Range in standardized values	Average values, 1927–30	Range in standardized concentrations, p.p.m.	Average nitrate concentrations 1929–31, p.p.m.	
Ps + K.....	Very low	0–2	1.7	0–100	198	42.7
Ps.........			1.8		142	34.8
N(ams) + Pr	Slightly low	2–3	2.7	100–300	151	38.0
Pr.........	Ample, but not high	3–4	3.2	300–400	365	28.5
N..........			3.6		214	14.6
N + Ps.....			3.6		227	29.2
K..........			3.8		330	35.8
N + Ps + K.	High	4–5	4.1	400 +	208	47.1
M + Pr....			4.4		507	48.6
N + K.....			4.5		688	38.7
M (plat 12)..			4.5		706	50.3
M + Ps....			4.5		807	40.8
M (plat 10)..			4.9		669	47.5

*Check, no treatment since 1909; N, nitrogen from dried blood; N(ams), nitrogen from sulfate of ammonia; M, stable manure; Pr, rock phosphate; Ps, superphosphate; K, muriate of potash.

numerical values range from 0 to 5 and their meaning with reference to different nitrate levels is indicated in Table 2.

In reporting some preliminary results obtained with the sap-analysis method, Pettinger (3) suggested that less than 100 p.p.m. of nitrate nitrogen in the plant sap be regarded tentatively as very deficient, 200 p.p.m. as moderately deficient, and over 300 p.p.m. as an ample supply. More recent studies to be reported soon indicate that some of these tentative standards may need revision; nevertheless, the values listed above are used in Table 2 because they are sufficiently correct to be usable and because they are the only published standards available for corn.

The data in Table 2 are listed on the basis of increasing stalk-test values and are arranged in groups indicating different nitrate levels by the same method. It may be noted that the nitrate concentrations by the sap-analysis method show a marked tendency to increase with the stalk test values in accordance with the correlation coefficient +0.77 ± 0.076 quoted above. The high nitrate concentrations in the plant sap for the two plats listed as "very deficient" are the most glaring exception to this relation. However, the yields of corn grain indicate that these plats did not suffer acutely from a nitrogen deficiency. Although nitrogenous materials were withheld from the fertilizers applied, the presence of good stands of clover during 2 years of each rotation (4 years) has been responsible for a fair, although not ample, supply of nitrates in these plats. The experimental conditions under which the tests were made and familiarity with the performance of these two plats over a period of years indicate that the nitrate concentrations in the sap gave a more accurate estimate of the nitrate level than the stalk-test values and that the two plats classed as "very low" by the stalk test should be classed as "slightly low." The same conclusion may be drawn from the low nitrate concentrations in the saps from plants grown on the N + Ps and N plats in the "ample" nitrate group. Clovers have grown poorly on these plats in recent years because of mineral deficiencies. The nitrates were apparently ample for the conditions of mineral deficiencies under which the plants were grown, but in the event of no mineral deficiencies it is probable that the nitrate supply would have been inadequate and classed as "slightly low."

The nitrate estimations by the two methods show only a fair degree of correlation with the application of nitrogenous fertilizers. Table 2 shows that the plants with the lowest nitrate level received no nitrogen in fertilizers and that the plants having a high nitrate level received fertilizers containing nitrogenous materials. In these cases, the degree of correlation is high between the nitrate level in the plants and nitrogen fertilization. However, Table 2 shows also that some of the plats which received no nitrogenous fertilizers produced plants containing an ample supply of nitrates, and plat 4, which has received 200 pounds of ammonium sulfate per acre annually, produced plants with an inadequate supply of nitrates.

In explaining the lack of perfect correlation between nitrogenous fertilization and nitrate levels, it should be kept in mind that in the present experiments the need for nitrogenous fertilizers has been greatly reduced by the clover crops which have occupied the land for 2 years in each 4-year period. Where clovers are responsible for appreciable quantities of the nitrogen supplied to the test crop, the addition of commercial nitrogen may or may not give an additional response. Under these conditions the degree of correlation between the application of nitrogenous fertilizers and nitrate levels will be inversely proportional to the effectiveness of the clover crop in supplying the test crop with nitrates. As the effect of the clovers is high, medium, or low, the influence of nitrogenous fertilizers in determining either the nitrate supply or the nitrate level in the plant would be expected to be low, medium, or high, respectively.

In this connection it should be pointed out that it is neither essential nor important for any test method to show a high degree of correlation between nitrogenous fertilization and the nitrate supply in order to be considered as a good and reliable method. With some soils this also would be true for phosphorus and potassium, although generally to a lesser degree than for nitrogen. The important relation so far as the stalk-test and sap-analysis methods are concerned is the parallelism between the nitrate level in the plant and the nitrate supply in the soil. So far as test methods are concerned it is immaterial whether the nitrates were contributed by added fertilizer materials or by native soil substances. Test methods must determine the current status of the nitrate supply without reference to the source of this plant food constituent. It is evident also from the data already presented and from the experimental conditions under which the tests reported herein were conducted that both the stalk-test and sap-analysis methods showed the nitrate levels in the plants to be more strongly correlated with the nitrate supply in the soil than with the application of nitrogenous fertilizers.

COMPARISONS OF METHODS FOR AVAILABLE PHOSPHORUS TESTS

A comparison of methods for determining the adequacy of the available phosphorus supply is limited here to the Neubauer and sap-analysis methods for the reason that the Hoffer stalk-test method does not include a direct test for this element. Soil and sap samples were collected in each year of the period of 1928–31, inclusive. The sap samples were analyzed for total phosphorus each year as the plant-sap investigations progressed, but the soil samples were all preserved until 1932 when they were tested by the Neubauer procedure. The results of the analyses are given in Table 3.

These data show that the application of effective phosphorus carriers brought about substantial increases in both the Neubauer values and the quantity of total phosphorus in the plant sap. The available phosphorus levels as indicated by the two methods are therefore closely correlated with phosphatic fertilization.

It is also apparent from the data in Table 3 that there is excellent agreement between the available phosphorus supplies in the various plats as indicated by the two methods. The degree of agreement between the two methods is shown more clearly in Table 4 where the average Neubauer values and the average quantities of total phosphorus in the plant sap are arranged in groups which cover different

TABLE 3.—*Available phosphorus tests by the Neubauer and sap-analysis methods for 1928 to 1931, inclusive, on plats receiving different fertilizer treatments.*

Plat No.	Fertilizer treatment*	Neubauer values, mgms P_2O_5 per 100 grams dry soil					Sap-analysis values, mgms P_2O_5 per cc of sap				
		1928	1929	1930	1931	Ave.	1928	1929	1930	1931	Ave.
$2X_2$	Ps	7.6	6.4	9.7	6.2	7.5	0.36	0.28	0.33	0.22	0.28
$3X_2$	N + Ps + K	7.3	6.5	7.7	6.0	6.9	0.23	0.22	0.21	0.23	0.22
$4X_1$	Check	1.9	1.6	0.7	1.1	1.4	0.11	0.05	0.12	0.10	0.10
$4X_2$	N(ams) + Pr	3.8	2.1	2.3	1.8	2.5	0.21	0.13	0.16	0.13	0.16
$5X_2$	Ps + K	6.1	4.6	5.9	5.5	5.5	0.25	0.17	0.30	0.26	0.25
$6X_2$	K	2.2	1.2	1.6	2.0	1.8	0.15	0.04	0.12	0.09	0.10
$7X_2$	N +K	2.3	1.3	1.8	0.9	1.6	0.12	0.04	0.08	0.10	0.09
$8X_2$	N + Ps	8.3	4.1	5.0	4.5	5.5	0.36	0.16	0.35	0.29	0.29
$9X_2$	N	2.9	1.6	2.0	2.1	2.2	0.22	0.05	0.14	0.13	0.14
$10X_2$	M	5.2	2.8	4.7	3.0	3.9	0.25	0.11	0.19	0.21	0.19
$11X_1$	Check	0.6	0.9	1.8	1.4	1.2	0.11	0.10	0.15	0.18	0.14
$11X_2$	M + Pr	3.9	2.4	5.1	3.9	3.8	0.24	0.15	0.15	0.21	0.19
$12X_2$	M	4.1	2.6	3.7	3.7	3.5	0.26	0.14	0.28	0.24	0.23
$13X_2$	M + Ps	9.7	6.8	7.7	9.7	8.5	—	0.24	0.34	0.40	0.36
$14X_2$	Pr	0.6	0.9	1.9	1.2	1.2	0.11	0.04	0.23	0.19	0.14

*Check, no treatment since 1909; N, nitrogen from dried blood; N(ams), nitrogen from sulfate of ammonia; M, stable manure; Pr, rock phosphate; Ps, superphosphate K, muriate of potash.

portions of their respective value ranges. The plats are listed in order of their increasing Neubauer values, and it may be noted that without exception all of these values fall within the range limits of their respective groups. With but one exception the average quantities of total phosphorus found in the various sap samples also fall within the limits of their respective groups. The two sets of data parallel each other so closely as to give a correlation coefficient of +0.92 ± 0.028. This high coefficient, of course, indicates that the Neubauer and sap-analysis methods were in nearly perfect agreement in estimating the supplies of available phosphorus in the various plats.

It is of interest also to note from Table 3 that with but one exception these two methods are in perfect agreement in correlating the different levels of available phosphorus with the relative capacities of the different phosphorus carriers to supply available phosphorus at the rates used. Thus, the first group of the table contains the lowest Neubauer and sap-analysis values, and it may be noted that five of the six plats in this group received no phosphorus carriers. The only exception in the whole table occurs in this first group where plat 14, which has received rock phosphate annually, has given low values. Nevertheless, the two methods are in agreement in showing the slow availability of the phosphorus in this carrier. The second group is made up of the plats which have received either rock phosphate or stable manure, or both. The phosphorus in rock phosphate has been found to be only slowly available and that in stable manure, while quite readily available, has been added in such quantity as to be equivalent to only about 20 pounds P_2O_5 per acre annually. The

TABLE 4.—*Different levels of available phosphorus as shown by the Neubauer and sap-analysis methods, and their correlation with the application of phosphatic fertilizers.*

Plat No.	Fertilizer treatment*	Neubauer values, mgms P_2O_5 per 100 grams dry soil		Sap-analysis data, mgms P_2O_5 per cubic centimeter of sap		Yield of corn grain, bushels per acre
		Determined	Range	Determined	Range	
$11X_1$	Check	1.2	0.0–2.5	0.14	0.05–0.15	20.1
$14X_2$	Pr	1.2		0.14		28.5
$4X_1$	Check	1.4		0.10		29.2
$7X_2$	N + K	1.6		0.09		38.7
$6X_2$	K	1.8		0.10		35.8
$9X_2$	N	2.2		0.14		14.6
$4X_2$	Pr + N(ams)	2.5	2.5–5.0	0.16	0.15–0.20	38.0
$12X_2$	M	3.5		0.23		50.3
$11X_2$	Pr + M	3.8		0.19		48.6
$10X_2$	M	3.9		0.19		47.5
$5X_2$	Ps + K	5.5	5.0–7.5	0.25	0.20–0.30	42.7
$8X_2$	Ps + N	5.5		0.29		29.2
$3X_2$	Ps + N + K	6.9		0.22		47.1
$2X_2$	Ps	7.5		0.28		34.8
$13X_2$	Ps + M	8.5	7.5 +	0.36	0.30 +	40.8

*Check, no treatment since 1909; N, nitrogen from dried blood; N(ams), nitrogen from sulfate of ammonia; M, stable manure; Pr, rock phosphate; Ps, superphosphate, K, muriate of potash.

third group contains all of the plats which received superphosphate as the only supplementary source of phosphorus, and the fourth group, where the highest values were obtained by both methods, received superphosphate and stable manure, both of which are regarded as sources of readily available phosphorus. Hence, it is evident that the test-method values increase by groups in accordance with the capacities of the different carriers to supply available phosphorus. This shows that both the Neubauer and sap-analysis methods gave very accurate estimations of the relative supplies of available phosphatic compounds in the plats used in the study reported herein. The data show no superiority of one method over the other in this respect.

The excellent agreement between the two methods for estimating available phosphorus is also emphasized by the following data which show the average increases that the different phosphorus carriers were able to effect in the Neubauer values and in the total phosphorus content of the sap:

	Neubauer values	Mgm P_2O_5 per cc of sap
By rock phosphate	0.1	0.01
By stable manure	2.1	0.08
By superphosphate	4.7	0.15

The increases are much larger numerically in the Neubauer values than in the sap values, but this is to be expected because the Neubauer values ranged up to 8.5 mgms in the present experiments, while the sap values ranged only to 0.36 mgms. The increases due to applications of stable manure were therefore about one-fourth of the total range for each method and the increases due to superphosphate were about one-half of the entire range of each method.

COMPARISONS OF METHODS FOR AVAILABLE POTASSIUM TESTS

The potassium tests permit of a comparison of all three of the methods studied. The stalk-test method was used from 1927–30, inclusive, while the Neubauer and sap-analysis methods were used from 1928–31, inclusive. The data obtained by means of the three methods are given in Table 5.

These data show that there is excellent agreement between potassium fertilization and the magnitude of the test values indicating available potassium. It will be noted that the plats are separated into two well-defined groups. The first group contains the plats which have received no potassium carriers. For this group the test values for available potassium are all comparatively low. The second group contains all of the plats which have received potassium carriers regularly for more than 20 years. For this group the test values are all comparatively high.

It is also apparent from Table 5 that the average test values obtained by the different methods are well correlated with each other. This is shown by the following correlation coefficients:

Between average Neubauer and sap-analysis values,	+0.92±0.027
Between average Neubauer and stalk-test values,[4]	+0.96±0.014
Between average sap-analysis and stalk-test values[4],	+0.96±0.013

GENERAL DISCUSSION

The usefulness of any of the so-called rapid methods for determining the nutrient needs of soils is judged (a) by its ability to reflect the available nutrient supply accurately and (b) by its adaptability to rapid use. Accuracy is, of course, the first requisite to establishing confidence in the results obtained by any method. It is immaterial how many good features a method may have, if accuracy is not one of them, it is for the most part useless. On the other hand, undesirable features may often be tolerated to a considerable degree when a method assures accurate results.

However, different investigators are not always in agreement as to what constitutes sufficient accuracy in a test method. Although a part of this disagreement may be due to the diverse nature of the different methods which have been proposed, it is true also that some investigators apparently judge the value of test methods by the extent to which they can be molded into quantitative form, while

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[4] The stalk-test values in Table 5 are given in terms of accumulated iron. However, since Hoffer (1, 2) has shown an inverse relation between iron accumulations and the supply of available potassium, the correlation coefficients have been made to relate to the available potassium indices obtained by the two methods.

TABLE 5.—*Available potassium tests by the Neubauer, sap-analysis, and stalk-test methods for 1928 to 31, inclusive, on plats receiving different fertilizer treatments.*

Plat No.	Fertilizer treatment*	Neubauer values, mgms K_2O per 100 grams dry soil					Sap-analysis values, mgms K_2O per cc of sap					Hoffer stalk-test values†					Yield of corn grain, bushels per acre
		1928	1929	1930	1931	Ave.	1928	1929	1930	1931	Ave.	1927	1928	1929	1930	Ave.	
$8X_2$	N+Ps	3.0	0.6	1.8	1.8	1.8	0.44	0.83	0.64	0.90	0.70	3.7	3.4	4.5	3.3	3.7	29.2
$9X_2$	N	3.6	0.6	1.8	2.4	2.1	0.39	0.54	0.66	0.42	0.50	5.7	2.4	4.3	2.5	3.7	14.6
$14X_2$	Pr	1.8	1.2	7.3	—	3.4	0.51	0.76	1.37	0.84	0.87	2.7	3.8	3.5	2.0	3.0	28.5
$11X_1$	Check	2.4	6.1	3.0	6.1	4.4	0.45	0.35	0.70	1.03	0.63	—	—	4.3	2.8	3.6	20.1
$4X_2$	N(ams)+Pr	6.7	6.1	4.2	3.6	5.2	0.36	0.74	0.54	0.50	0.54	4.0	2.4	3.8	2.3	3.1	38.0
$4X_1$	Check	7.9	6.7	6.1	4.2	6.2	0.48	0.97	1.81	1.07	1.08	—	—	3.0	1.3	2.2	29.2
$2X_2$	Ps	11.5	12.1	9.7	4.8	9.0	0.58	1.20	1.08	0.61	0.87	3.7	2.0	3.8	1.3	2.7	34.8
$13X_2$	M+Ps	14.5	15.1	15.7	23.0	17.1	—	5.04	4.90	4.86	4.93	—	0.0	1.0	0.8	0.6	40.8
$5X_2$	Ps+K	13.3	19.4	12.7	26.6	18.0	6.00	7.17	4.97	6.02	6.04	0.7	0.2	1.5	0.5	0.7	42.7
$7X_2$	N+K	16.9	16.3	19.4	21.8	18.6	5.62	4.90	4.64	5.34	5.12	0.0	0.4	1.0	2.3	0.9	38.7
$11X_2$	M+Pr	15.7	17.5	24.2	19.4	19.5	6.35	5.72	6.25	3.57	5.50	0.3	0.0	1.0	0.0	0.3	48.6
$3X_2$	N+Ps+K	20.6	26.0	21.7	18.2	21.4	5.94	4.03	4.99	6.20	5.12	0.7	0.2	1.8	0.5	0.8	47.1
$10X_2$	M	20.6	21.8	23.0	20.6	21.5	6.24	4.50	5.08	4.26	5.02	—	0.2	1.5	0.5	0.7	47.5
$6X_2$	K	15.7	18.2	29.0	29.6	23.1	5.39	5.52	3.84	4.64	4.85	0.0	0.6	0.8	1.5	0.7	35.8
$12X_2$	M	19.4	20.0	29.0	24.2	23.2	6.40	5.58	6.37	4.98	5.83	0.0	0.0	1.3	1.3	0.7	50.3

*Check, no treatment since 1909; N, nitrogen from dried blood; N(ams), nitrogen from sulfate of ammonia; M, stable manure; Pr, rock phosphate, Ps, superphosphate; K, muriate of potash.

†Data indicate intensity of iron accumulations. Stalk tests made by W. P. Allyn in 1927, 1928, and 1929.

others feel that a qualitative diagnosis is all that is necessary from the practical point of view. The former group places considerable emphasis on the importance of the individual test and its expression in quantitative terms and the formulation of a quantitative scale of nutrient estimates and corrective treatments. The latter group, while recognizing that it is always desirable to attain as much accuracy as possible, feel that a knowledge of whether the nutrient level is low or ample provides a sufficient basis on which to prescribe corrective treatments under most farming conditions. The data presented above show that the Neubauer, sap-analysis, and Hoffer stalk-test methods gave sufficiently accurate estimates of the different nutrient levels to allow them to be used with confidence in diagnostic work irrespective of whether the qualitative or quantitative viewpoint is held in greater favor.

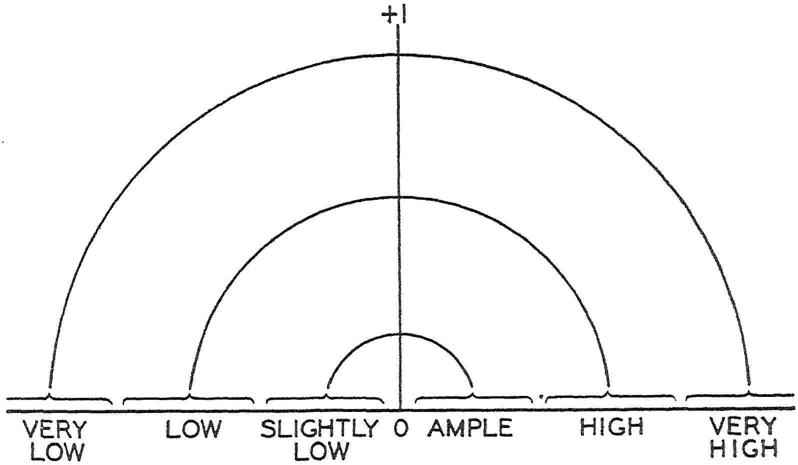

FIG. 1.—Degree of agreement which may be expected when test values obtained by different methods in different portions of the available nutrient range are correlated.

A criticism sometimes heard of certain test methods is that, although they reflect acute deficiencies and abundant supplies of available nutrients quite accurately, they are not dependable for border-line cases (4). In this connection it should be pointed out that any method may be expected to give less positive results over that portion of the available nutrient range which lies between definite deficiency on the one end and an abundant supply on the other end (Fig. 1). The main reason for this is that when the available supply of any nutrient is just sufficient to meet the needs of the crop, it can readily be made to appear either deficient or abundant by changes in the availability of other nutrients or through the operation of other possible limiting factors. Thus, a slightly deficient supply of nitrates may be made to appear to be ample when mineral deficiencies develop. On the other hand, what appears to be an ample supply of nitrates under conditions of mineral deficiencies may be reduced to a deficiency status when the assimilation of nitrates is increased through a correction of other deficiencies. The utilization of any of the principal nutrient ions in the plant is so often dependent on the availability of other nutrient ions, that the accumulation or disappearance of any ion may be due as much to changes in the availability of supplementary ions as to the capacity of the soil to supply the nutrient under test in an available form. Also, the effects of other limiting factors are most noticeable in the test-method indices when the nutrient under test is approximately ample for crop needs. When the nutrient under test is either acutely deficient or very abundant, other limiting factors do not have sufficient effect to alter greatly the level of availability. The low values will remain comparatively low and the high values will remain high, regardless of the effect of other factors. At the extreme ends of the available nutrient range (Fig. 1), therefore, the test values are nearly always definite, and the indices obtained by different methods usually show excellent agreement. But at the center of the available nutrient range, where the effects of other limiting factors on the disappearance or accumulation of the nutrient under test have a better chance of showing up, the indices by different methods may show poor agreement.

From this it follows also that the magnitude of the correlation coefficients, when used as a measure of the degree of agreement between different test methods, will be determined partially by the extent to which the entire available nutrient range is represented in the soils being tested. This is shown schematically in Figs. 1 and 2. If the soil areas being tested represent only the mid-section of the available nutrient range, poor agreement between different test methods may be obtained because the influences of other limiting factors as discussed above may be sufficient to give contradictory results in some cases. On the other hand, if only the extreme ends of the available nutrient range are represented in the soil areas under test, the degree of agreement between different methods should be high for the reason that the nutrient indices in these portions of the available nutrient range are usually positive by any method. The effect of correlating the test values in different portions of the available nutrient range on the magnitude of the resulting coefficient is shown in Fig. 1 by the semicircles which connect these different portions and the points at which they intersect the correlation scale. Fig. 2 shows the relative changes which may be expected in the magnitude of the correlation coefficients when the test values *within restricted portions* of the available nutrient range are correlated. The changes indicated here are largely the resultant of the increasing positiveness and agreement between the indices obtained by different test methods as the ends of the available nutrient range are approached, and the increasing possibility for discordant results in the center of the range where the nutrient levels are approximately adequate for crop needs and are susceptible to the modifying effects of other growth factors as outlined above.

It is the opinion of the writers that some of the poor agreement between different test methods reported by various investigators may be explained on the basis of the relations shown in Figs. 1 and 2. In some cases, it seems evident that comparisons have been made in which the soils used represented only a limited portion of the available nutrient range. Old fertility plats, such as are now available at many experiment stations, where fertilizers have been either withheld or applied for many years, are often used for testing and comparing diagnostic methods. The nutrient levels are well established and are usually either high or low. While such plats furnish an excellent place to test methods over the end portions of the available nutrient range, it should be kept in mind that the central portion of the range is often poorly represented or not at all. Under conditions of this kind, test methods sometimes receive unjust criticism from the investigator because of his own failure either to provide conditions under which the methods may be tested accurately and judged fairly, or to take into account the limitations imposed by samples which cover only limited portions of the available nutrient range.

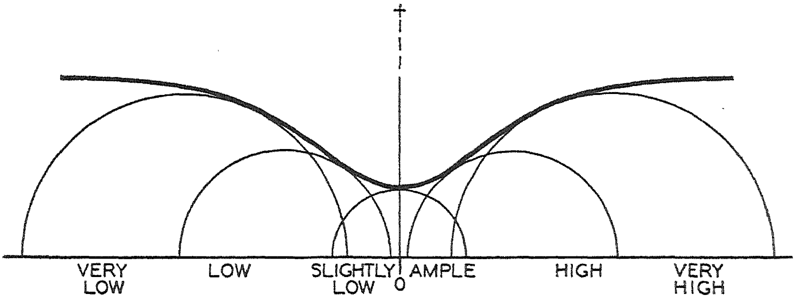

FIG. 2—Relative changes which may be expected in the degree of agreement between test values obtained by different methods within restricted portions of the available nutrient range when the correlation coefficient is used as a measure of such agreement.

In the light of these considerations it may be of interest to determine to what extent the available nutrient ranges for nitrogen, phosphorus, and potassium were represented in the plats used in the present study. On the deficiency end of the range, the corn-grain yields given in Tables 2, 4, and 5 show that the soil was only slightly deficient in nitrogen, while phosphorus and potassium were markedly deficient, potassium being slightly more so than phosphorus. Nitrogen was less deficient where no fertilizers have been added than either phosphorus or potassium because of the presence of clover in the rotation. As for the other end of the range, it will be sufficient to point out that the commercial fertilizers used have supplied 40 pounds of nitrogen per acre annually, phosphorus at the rate of 70 pounds P_2O_5 per acre annually, and potassium at the rate of 100 pounds K_2O per acre annually. On both ends of the range, then, the portions covered by the three elements are in the order of $N \langle P \langle K$. It may be recalled, too, that the agreement between the different test methods as indicated by the magnitude of the correlation coefficients was also in the order of $N \langle P \langle K$. These two orders are therefore in agreement in showing that the plats used gave nitrogen more representation in the center of the available nutrient range where correlation coefficients may be expected to be lower (Fig. 2) than was the case with either phosphorus or potassium. Table 4 shows that all portions of the available phosphorus range were represented, and it is therefore evident that the Neubauer and sap-analysis methods were in excellent agreement over the center portion of the range as well as over the end portions. However, the high correlation coefficients obtained between the available potassium estimates by different methods must be given a different interpretation. Table 5 shows that all of the estimates are either very low or high. Hence, the center portion of the range was not represented, and the outer portions of the range would be expected to give excellent agreement by any method (Fig. 1). While it is true that the available potassium estimates obtained by the three methods used were in excellent agreement and would therefore give a high correlation coefficient, the fact remains that the soils tested represented only those portions of the available potassium range which are most likely to give excellent agreement and high coefficients.

SUMMARY AND CONCLUSIONS

The studies reported in this paper deal with comparisons between the Neubauer, sap-analysis, and Hoffer stalk-test methods for determining the available nitrogen, phosphorus, and potassium needs of soils. The study covers the 5-year period 1927–31, inclusive.

The average nitrate values obtained by the stalk-test and sap-analysis methods were correlated to the extent of +0.77±0.076. Under the conditions of the experiment this is considered to be good agreement. Because of the presence of clover in the rotation, the nitrate estimates by these two methods show only a fair degree of correlation with the application of commercial nitrogenous materials.

The average available phosphorus estimates obtained by the Neubauer and sap-analysis methods were correlated to the extent of +0.92 ± 0.028, and therefore show nearly perfect agreement. The values obtained by these two methods were also in excellent agreement with phosphatic fertilization and in estimating the effectiveness of the different phosphorus carriers used.

The average available potassium estimates by the Neubauer, sap-analysis, and stalk-test methods were all strongly correlated, and therefore in excellent agreement. The following correlation coefficients were obtained:

Between average Neubauer and sap-analysis values,	+0.92±0.027
Between average Neubauer and stalk-test values,	+0.96±0.014
Between average sap-analysis and stalk-test values,	+0.96±0.013

A discussion is given of the interpretation and limitations of correlation coefficients as a measure of the agreement between test-method values in different portions of the available nutrient range.

LITERATURE CITED

1. HOFFER, G. N. Testing corn stalks chemically to aid in determining their plant food needs. Purdue Univ. Agr. Exp. Sta. Bul. 298. 1926.

2. HOFFER, G. N., and TROST, J. F. Accumulation of iron and aluminum compounds in corn plants and its probable relation to root rots, II. Jour. Amer. Soc. Agron., 15 : 323–331. 1923.
3. PETTINGER, N. A. The expressed sap of corn plants as an indicator of nutrient needs. Jour. Agr. Res., 43 : 95–119. 1931.
4. STEWART, L. C., SACKETT, W. G., ROBERTSON, D. W., and KEZER, ALVIN. A comparison of the soil-plaque method with the Neubauer and Hoffer cornstalk methods for determining mineral soil deficiencies. Col. Agr. Exp. Sta. Bul. 390. 1932.
5. THORNTON, S. F. Experiences with the Neubauer method for determining mineral nutrient deficiencies in soils. Jour. Amer. Soc. Agron., 23 : 195–208. 1931.
6. ————. A field and laboratory test on plant material for diagnosing phosphorous deficiencies. Purdue Univ. Agr. Exp. Sta. Bul. 355. 1932.
7. ————. A simple and rapid chemical test on plant material as an aid in determining potassium needs. Jour. Amer. Soc. Agron. 25 : 473–481. 1933.
8. WINSTON, R. A., and LEE, ORA. Soil survey of Montgomery County, Virginia. U. S. D. A. Bur. Soils. 1908.

THE EFFECTIVENESS OF TEN YEARS OF AGRONOMIC EXTENSION WORK IN THE MISSOURI CLOVER AND PROSPERITY PROGRAM[1]

IDE P. TROTTER[2]

For 10 years the Missouri "Clover and Prosperity Program" has occupied a prominent place in the agronomic extension work of the state. The authors[3] of this plan outlined it fully before the American Society of Agronomy at Washington in 1924. Now that the program has been in actual operation for 10 years, there is presented here briefly the plan and the progress obtained during that time, together with results of studies made as to the effectiveness of the program in changing the legume practices of Missouri farmers.

DESCRIPTION OF THE PROGRAM

Missouri farmers, in common with those of most other states, have long been in need of a greater acreage of legumes to round out properly their diversified type of agriculture and to provide properly for their large livestock population. One purpose behind the launching of the clover and prosperity program was to analyze this problem and to organize an approach to its solution so as to make the time and money spent on legume work, both in investigation and extension, most effective. The authors of the program outlined its three major phases as follows:

I. A propaganda phase—to arouse interest and convince farmers of the value of legumes.

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[1] Contribution from the Agricultural Extension Service, University of Missouri, College of Agriculture, Columbia, Mo. Abstract of a thesis submitted in partial fulfillment of the requirements for the degree of doctor of philosophy at the University of Wisconsin. Also presented at the annual meeting of the Society held in Chicago, Illinois, November 16 to 17, 1933. Published with the consent of the Director of Extension. Received for publication October 26, 1933.

[2] Extension Assistant Professor of Field Crops.

[3] CARTER, C. E. and SCHOWENGERDT, P. F. A state-wide campaign for more legumes. Jour. Amer. Soc. Agron., 17 : 431–439. 1925.

II. The educational phase—to demonstrate the place of legumes in a system of farming and how to grow them.

III. The adoption phase—to secure adoption of the practices by *masses* through intensive community campaigns and by such organization work as is necessary to make it easy for farmers to get seed, materials, etc.

The propaganda phase in each county was build around an all-day legume meeting, widely featured in publicity, which initiated the movement locally. There the soils and crops specialists explained the problem and the proposed solution with the aid of a truck load of exhibit material. This phase of the program was carried out in 95 of the 114 counties in Missouri.

The educational phase was initiated the following winter with the organization of a "Clover and Prosperity Conference" for each county. To this conference were invited, by official appointment from the county court, one or more carefully selected delegates from each of the old original school districts of the county, thus insuring county. wide representation of the leading farmers who might be expected to help mould opinions and practices in their communities. At the first of these conferences the problem was analyzed more carefully and the solution agreed upon. A long-time demonstration program was proposed as the basis of the solution and one was immediately launched by volunteer demonstrators. Annually thereafter this group of delegates were reassembled, the plan reviewed, reports given as to progress made in solving the problem of legume production, and plans outlined for the work of the next year. This phase of the program has reached 99 of the 114 counties of the state and 32 counties have been holding their conferences regularly each winter since the inauguration of the program with steadily increasing interest and attendance through the 9 years already past. For several years more than 10,000 of these selected local leaders all over the state have assembled in their county conference each winter to continue their work on this program.

No further details of the mechanics of the program under consideration can be given here other than to say that this program for doing soils and crops extension work is believed to be unique in the following features:

1. It is the first large-scale, long-continued test of the discussion method of teaching adult farmers new agricultural practices.
2. It works through conferences of farmers chosen as representatives of and leaders in their local communities.
3. It attacks basic problems annually in an organized long-time program.
4. Each annual conference for discussion is county-wide, and the whole program is state-wide in its scope.
5. The program adopted by the conference is executed as a year-round program.
6. The solutions proposed are locally tested and proved.
7. All important legume crops are included. No one crop is presented as a cure-all.
8. Many well-recognized means of influencing behavior are used.

9. They are applied and developed over a long period of years, being continually adapted to local and changing conditions.

PLAN OF INVESTIGATION

Research in the field of extension is relatively new and has been handicapped by inability to control conditions or to find situations in which conditions remained reasonably similar over a considerable period of time. Realizing these limitations and the need for more research in this field, this investigation was planned to take into account more fully than in previously reported studies the variations occurring in both the use of and the individual and group exposure to the influence of the teaching methods used. A check sample or control group was included.

In this study we undertook to determine what changes of behavior had been made in the growing and treating of sweet clover by farmers who had attended the clover and prosperity conferences, when these changes were made, and how the time of these changes related to (1) the amount of participation the individual had had in the conferences and (2) the stage of the program's progress in the particular county, regardless of the amount of the individual's participation in the conferences. Against such data it was desired to compare the similar changes made by average farmers in areas having had (1) none of this type of work, (2) 3 years of this program, and (3) 6 years of this program.

Reports were secured (1) from 6,197 local leaders at clover and prosperity conferences in 89 of the 114 counties in Missouri who were directly exposed to the influence of the teaching methods, and (2) from 561 farms by a personal survey of all farmers residing in certain areas of three sample counties[4], most of whom were not directly exposed to the influence of the teaching method.

BASIC ASSUMPTIONS

The reliability of the data secured in this study is dependent upon the validity of three major assumptions as follows:

1. That the changes actually made are a valid measure of the amount learned of the subject matter taught.
2. That the farmer will be able to recall and record the objective facts called for about his farm and himself, as well as those about his operations and changes.
3. That averages secured from a number of such records will be an accurate representation of the actual changes made.

FINDINGS

Table 1 presents the findings as to the average number of different legumes grown per man associated with the number of conferences he has attended.

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[4] This phase of the study was conducted in cooperation with M. C. Wilson, in charge of extension studies and teaching, Office of Cooperative Extension Work, U. S. Dept. of Agriculture. For a further report of the results of this study see the following:

WILSON, M. C., and TROTTER, IDE P. Results of legume extension in three southeast Missouri counties representing three stages in the development of a state-wide legume program. U. S. D. A. Ext. Serv. Circ. 188. 1933.

TABLE 1.—*Average number of legume crops grown per man.*

Number conferences attended	Number farmers reporting	Number different legumes grown per man
One	1,814	2.23
Two	1,390	2.41
Three	810	2.58
Four	808	2.75
Five	415	2.90
Six	502	2.99
Seven	319	3.20

As the number of conferences attended increased, the number of different legumes grown per man likewise increased from 2.23 for the 1,814 farmers who attended only one conference to 3.20 for the 319 farmers who attended seven conferences. We than have an average increase of 0.97, or 43.5% in the number of different legumes grown per man associated with six years of attendance at conferences. On the basis of these data there is an average increase of 7.25% in the number of different legumes grown per man which is associated with each year of attendance at clover and prosperity conferences.

An analysis of the sweet clover practices of local leaders by the amount of individual participation in the conference is presented in Table 2.

TABLE 2.—*Sweet clover practices of local leaders by the amount of individual participation.*

Number conferences attended	Percentage of those who			
	Grow	Inoculate	Fertilize	Lime
Seven	53.0	63.9	46.1	67.6
One	27.3	34.7	13.8	25.4
Increase for six conferences attended	25.7	29.2	32.3	42.2
Increase per conference attended	4.4	4.9	5.4	7.0

Table 2 is briefed from a more complete tabulation similar to that presented in Table 1. It shows that for each conference attended by the individual farmer there is an increase of 4.4% in the number who grow sweet clover, 4.9% in the number inoculating it, 5.4% in the number fertilizing it, and a 7.0% increase in the number liming for sweet clover.

At this point it should be emphasized that all of these increases are associated with attendance at the same conference and that sweet clover is only one of a half dozen legumes dealt with in the conference program. It merely happens to be the one selected for intensive study in this report of the effectiveness of the conference program in securing changes in farmers' legume practices. These data, therefore, should not be considered as measuring the total effectiveness of the conferences but rather as indicating the changes secured in the practices followed on one of a number of legume crops dealt with by the conferences.

A study of the time of adoption of sweet clover growing by farmers in certain stages of group progress in this program as compared to the time when the conferences were started in their counties is shown in Table 3.

TABLE 3.—*Time of adoption of sweet clover growing by 2-year averages for group participation* expressed in percentage.*

Years	4th conference counties	7th conference counties
Before clover and prosperity conferences started		
5 and 6	5.2	
3 and 4	18.0	
1 and 2	23.6	6.2
After clover and prosperity conferences started		
1 and 2	53.2	23.4
3 and 4		29.4
5 and 6		41.2

*In group participation all records from a county are entered at the county's stage of progress in the conference program regardless of individual variation in actual attendance at these conferences.

In the fourth-conference counties we note that whereas there has been a steady increase in sweet clover growing throughout the period studied, nevertheless, 53.2% of all the adoptions of sweet clover growing reported were secured in the 2 years after the conference program began, as contrasted with 46.8% secured in the entire 6-year period before the conference program began. In other words, we have over one-half of the total changes of practices reported coming in one-fourth of the time studied which could have been influenced by the teaching of the conference program. This would seem highly suggestive of a strong association between the teaching influence of the conference program and the adoption of the practice of growing sweet clover. Similarly, the seventh-conference counties show 41.2% of all the adoptions occurring in the last 2 years of the period studied.

A similar tabulation of the data on sweet clover growing secured from average farmers who had not been in direct contact with the program, but who resided in counties in the same stages of progress in the program, is given in Table 4.

From Table 4 we see that in a county where four conferences have been held, 52.0% of the average farmers who have adopted the practice of growing sweet clover during the last 8 years adopted it in the last 2 of those 8 years, which were the 2 years following the inauguration of the clover and prosperity conference program. In the group study of the fourth-conference counties the corresponding figure for the local legume leaders (Table 3) was 53.2%. In other words, the local leaders who attended the conferences and the average farmers who did not attend them show approximately the same time distribution in the adoption of sweet clover growing when we arrange the percentage changes in periods of 2 years from the time the con-

TABLE 4.—*Time of adoption of sweet clover growing by 2-year averages for average farmers expressed in percentage.*

Years	Four conferences held	Seven conferences held
Before clover and prosperity conferences started		
5 and 6	4.0	
3 and 4	20.0	
1 and 2	24.0	3.6
After clover and prosperity conferences started		
1 and 2	52.0	17.8
3 and 4		14.2
5 and 6		64.2

ferences started. But if these changes are studied by single years, in the ungrouped data not here reported, we find that the local leaders directly exposed show a sharply increased rate of change immediately after the program begins, whereas there is a lag of 1 year before this occurs among all farmers who are reached by indirect influence only.

These conferences appear to be selective for sweet clover growers. An approximate measure of this selectivity is developed in Table 5.

TABLE 5.—*Conference selectivity.*

	Percentage growing sweet clover
All attending for first time in 1931	27.3
Average farmers in no conference counties	11.8
Approximate factor for selectivity	15.5

Here we note that 27.3% of the farmers attending the conferences for the first time in 1931 report growing sweet clover, but only 11.8% of the average farmers in no-conference counties report growing sweet clover. The difference of 15.5%, though not attributable to selectivity alone, is taken as the approximate factor for selectivity of the conference for sweet clover growers.

We may now arrive at an indication of the value of direct as compared with indirect influence of the conference program (Table 6) in securing the adoption of the practice of sweet clover growing.

From these data we see that in the fourth-conference counties the farmers who attended all of them showed a 2.8% increase in growing sweet clover per year of participation over and above both the percentage of sweet clover growing by average farmers in counties in the same stage of conference progress and the approximate factor of conference selectivity for sweet clover growers. The similar figure for the seventh-conference counties is 3.4% per year. These give us a measure of the annual advantage of direct participation in the conferences as compared to the indirect influence of the conference program alone.

Likewise, Table 6 gives an indication of the cumulative value of repetition in bringing about a change of agricultural practices. Where-

TABLE 6.—*Direct vs. indirect influence.*

	Percentage growing sweet clover	
	4 conferences	7 conferences
Farmers attending all conferences	37.6	53.0
Average farmer, same conference stage	13.7	17.2
Difference favoring attendance	23.9	35.8
Conference selectivity factor	15.5	15.5
Increase for participation	8.4	20.3
Increase per year of participation	2.8 (3 years)*	3.4 (6 years)*

*The conference at which the report is made is not figured as participation because it had no effect on previous changes reported. Therefore, the years of participation are one less than years of attendance.

as the fourth-conference counties show an increase per year of participation of 2.8%, the seventh-conference counties show a similar increase of 3.4% per year. Further proof of this point is found in a study of the average farmer's sweet clover growing changes (Table 7), comparing various amounts of indirect influence from the conference program.

TABLE 7.—*Average farmer's changes in sweet clover growing.*

Comparing no conferences held with	Annual percentage increase
Four conferences held	0.83
Seven conferences held	0.90

Here we find that average farmers in counties where four conferences have been held show an annual percentage increase in the number growing sweet clover of 0.65 over and above that reported by average farmers in counties where no conferences have been held. A similar comparison of the reports of farmers in counties where seven conferences have been held and those where none have been held reveals an annual percentage increase in growing sweet clover of 0.90% in favor of those living in counties where seven conferences have been held. These two independent measures of the value of repetition in extension teaching would seem to indicate clearly the importance of so planning extension programs as to permit their continuance for a long enough period of time to take advantage of this very valuable cumulative effectiveness.

OTHER SIGNIFICANT FACTORS

Data were secured in this study on a number of other factors which were thought to be significant. The most interesting of these findings may be briefly summarized as follows:

1. The program is selective for farm owners. This increases with advancing stages of individual, but not with group, participation.

2. When farmers first participate in this program they average about 43 years of age and have spent about 15 years as the operator of the farm for which they report. Both of these items increase with

advancing stages of individual participation and at a slightly faster rate, neither of which occurs with group participation.

3. When farmers first participate in this program they have seen an average of about 0.5 demonstration each. This increases with advancing stages of both group and individual participation, being much more rapid with the latter.

4. There is a tendency for the average number of miles traveled by each local leader in coming to the conferences to decrease with advancing stages of both individual and group participation. But special interest groups, like sweet clover growers, traveled considerably farther to reach the conferences than the average of all farmers in the same stage of participation.

5. The amount of both limestone and commercial fertilizer used by each farmer in 1929 shows a slight tendency to increase with advancing stages of group participation. But with individual participation both items increase much more definitely, especially the limestone.

CONCLUSIONS

For the conditions described and from the results secured in this investigation, the following main conclusions may be drawn:

1. There is a close association between the amount of an individual local leader's exposure to the teaching methods used and the rate of change of his practices with regard to sweet clover. This does not occur with group exposure as defined in this study.

2. In a study of the effectiveness of teaching means and agencies in extension, it is essential to determine not only the fact of exposure, but also the time and amount of exposure, either direct or indirect, to the influence of the teaching means or agency.

3. When exposure to a teaching means or agency continues over a period of years it is found that the effectiveness in the later years is greater than in the earlier years both on those directly and indirectly exposed. This tendency to cumulative effectiveness is highly important.

4. The grouping of the data often conceals interesting or significant relationships between the teaching methods used and the associated changes of behavior and should therefore be done only when it does not not conceal relationships found in the ungrouped data.

RECOMMENDATIONS

The effectiveness of the teaching methods used in this program have been measured in terms of sweet clover practices adopted. In this program that was one of the subjects presented. The same methods might have been applied to the teaching of any other type of subject matter dealt with in agricultural extension work and the results might be expected to be somewhat comparable. Any significant findings in this study should, therefore, be of some value in suggesting methods of teaching which can be adapted to any field of extension teaching, whether in production, economics, social adjustment, or what not.

In view of the variations brought out by this study in the effectiveness of the means and agencies used in extension teaching, the administrative officers in charge of extension work should give more time and attention to research in this field. In no other way does it seem possible to secure the basic information which will be needed properly to guide decisions as to future plans and policies in extension work. Those in charge of such investigations will need to be thoroughly familiar with the subject matter taught, as well as its implications in the fields of education and sociology.

DECLINING NITRATE LEVELS IN PUTNAM SILT LOAM[1]

WM. A. ALBRECHT[2]

A 13-year study of the nitrate content of the surface soil of Putnam silt loam under cultivation reveals a gradual decline in the levels of the supply of this plant nutrient. The soil in question is a rolling phase of Putnam silt loam in a transition area approaching Lindley loam. It had been in grass for many years as pasture and as an undisturbed part of the station field previous to its use in this project. It was plowed as probably a native sod before this study was undertaken.

PLAN OF STUDY

During 13 years, 1920–32, inclusive, bi-weekly nitrate determinations (except when the soil was frozen) were made on the surface soil of a series of small plats. Some were continuously in corn, some in wheat, and some in fallow. Different tillage and fertilizer practices were combined with these crop treatments. During the first 6 years the wheat plats were plowed at different dates. The corn plats were given different tillage, while some of the fallow plats were given straw mulches. No plant nutrient additions were made. During the last 7 years all the plats were given standard tillage treatments supplemented with the more common fertilizer applications.

As an illustration of the general behavior of these nitrate levels, three plats have been selected as respesentative. One of these was in corn continuously for 13 years with the normal tillage treatment of spring plowing and surface cultivation, but given a spring treatment of ammonium sulfate (25 lbs. per acre) broadcast during the last 7 years. Another plat was in wheat continuously during the same time with regular plowing on August 15, followed by the customary treatment of seedbed preparation. During the last 7 years this was fertilized with the equivalent of 200 pounds of 2–12–0 at seeding. The third plat was fallow with a 6-ton straw mulch applied in late April following the spring plowing and after the removal of the straw in time to permit drying of the soil to a tillable condition.

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[1] Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo. Journal Series No. 369. Also presented at the annual meeting of the Society held in Chicago, Ill., November 16, 1933. Received for publication November 23, 1933.

[2] Professor of soils.

During the last 7 years, the equivalent of a 2-ton application of green manure in the form of chopped sweet clover or alfalfa was turned under each spring.

NITRATE CYCLES ACCORDING TO CROP AND SOIL TILLAGE

The numerous nitrate determinations have been assembled as monthly averages per advancing 5 years. Only the data for the growing season, March to October, inclusive, are presented. They are given as graphs in Figs. 1, 2, and 3 for these three respective plats for four of the nine advancing 5-year averages.

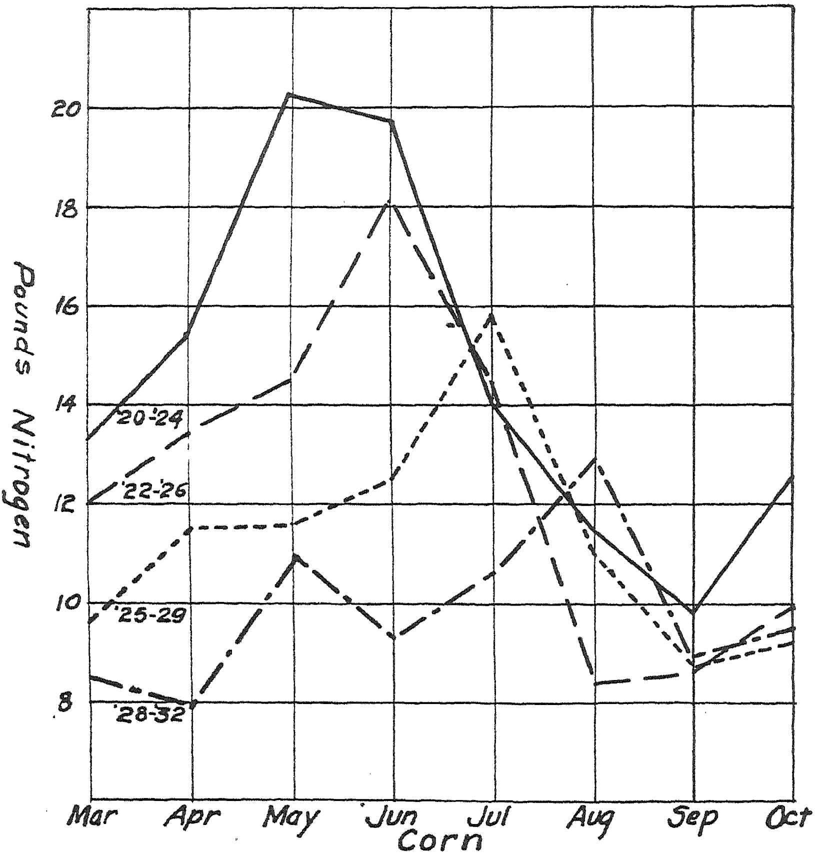

FIG. 1.—Nitrate nitrogen in the soil in corn. (Five-year averages during the growing season.)

The nitrate levels manifest certain cycles of seasonal variation with maxima at certain seasons and minima at others, each characteristic of the crop and the time of its seedbed preparation. For corn, the maxima are in the late spring and the minima are in the fall;

while for wheat these occur in early spring and early summer, respectively. The date of the season's maximum for corn varied, although the minimum occurred regularly in September. Under wheat, the season's maximum was found regularly in the early spring, while the low point occurred in June or July. The range between these two points was about the same for these two crops in the same year, but became less with succeeding years. The minimum under wheat was lower than that under corn. Under the fallow soil covered with the straw mulch, the nitrate levels were low at the beginning of the study in comparison with those under wheat, because of the depressive effects of the straw mulch. The seasonal cycle consisted of a small rise in May in consequence of the preceding removal of the straw mulch, the drying of the soil, and its tillage by the mould board plow. Following this rise, there was a gradual decline to a minimum in late summer.

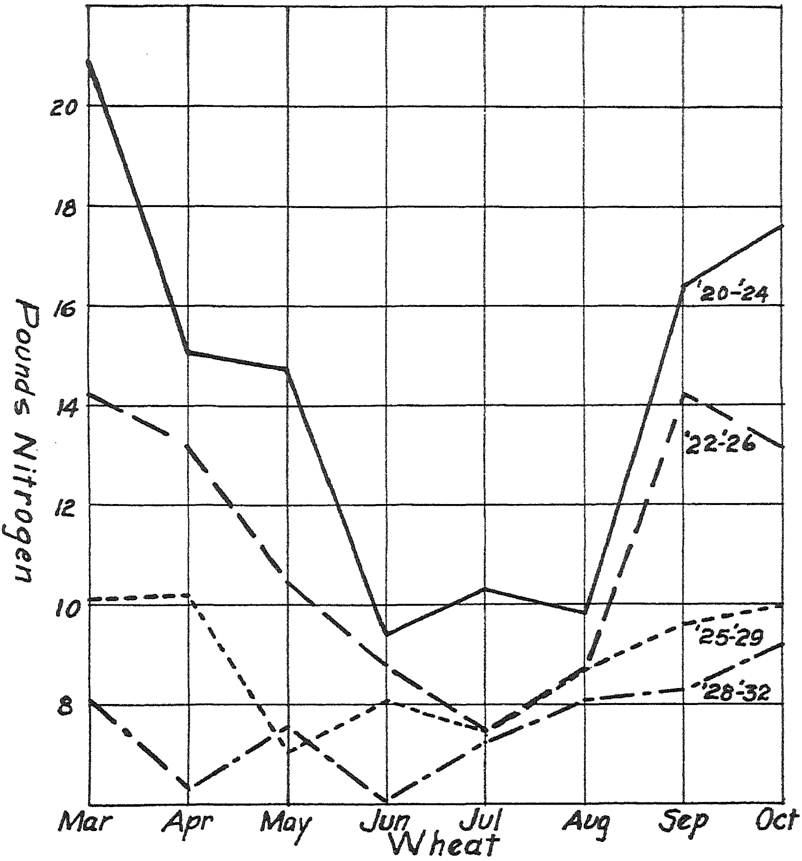

FIG. 2.—Nitrate nitrogen in the soil in wheat. (Five-year averages during the growing season.)

DECLINE IN NITRATE LEVELS WITH TIME

Perhaps the most significant fact established by these data is the decline of the nitrate levels in the soil with time, or the increasing failure of the soil to accumulate significant quantities of nitrate after several years of cropping. Figs. 1 and 2 show a decreasing range between the maximum and minimum levels for the successive growing seasons. The seasonal low point for the earliest years, 1920–24, namely, 9 pounds of nitrogen per acre for corn in September, was almost as low as any of the future minima. This seems to have been near the base level toward which the general nitrate content was falling as indicated by (a) the dropping of the successive maxima, and (b) their delaying to a later month in the year as the cropping to corn continued. This movement of the maximum point from May in 1920–24, to June in 1922–26, to July in 1925–29, and to August

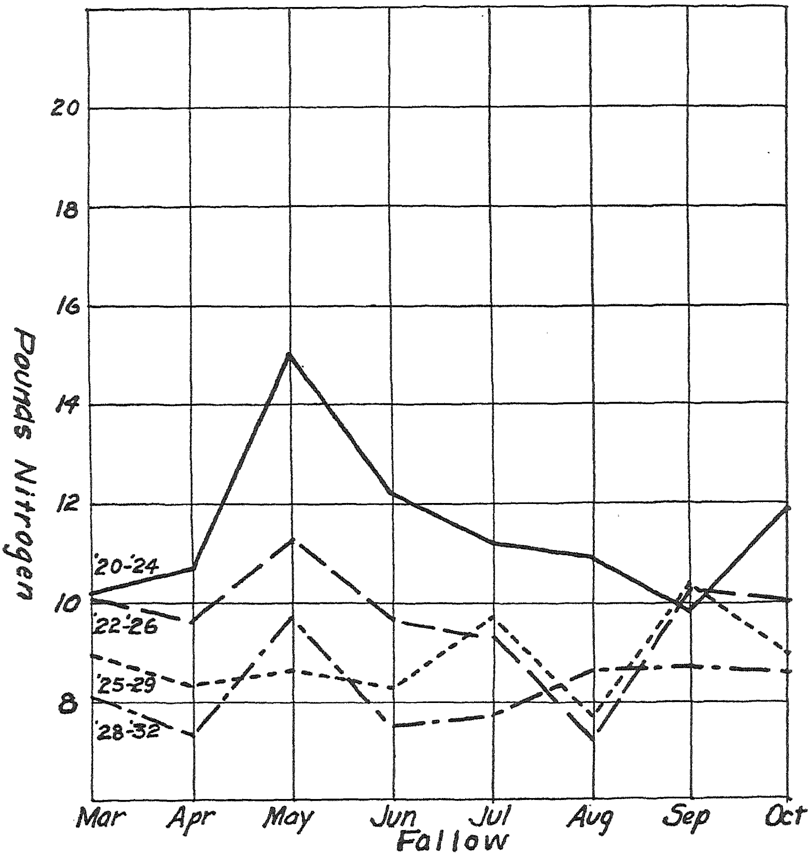

FIG. 3.—Nitrate nitrogen in straw-mulched fallow soil. (Five-year averages during the growing season.)

in 1928–32 suggests that the nature of the organic matter source of nitrate nitrogen was changing, possibly to those forms demanding higher temperature for significant nitrate release.

Under wheat a minimum point was also suggested at the early part of the study, though it did not so clearly indicate itself as a base level, as was true for corn. Later minima under this crop fell below that found at the outset. It is interesting to note that under wheat these lowest levels were significantly below those of corn. Even under the fallow soil (Fig. 3) the maximum levels of nitrate became lower with time.

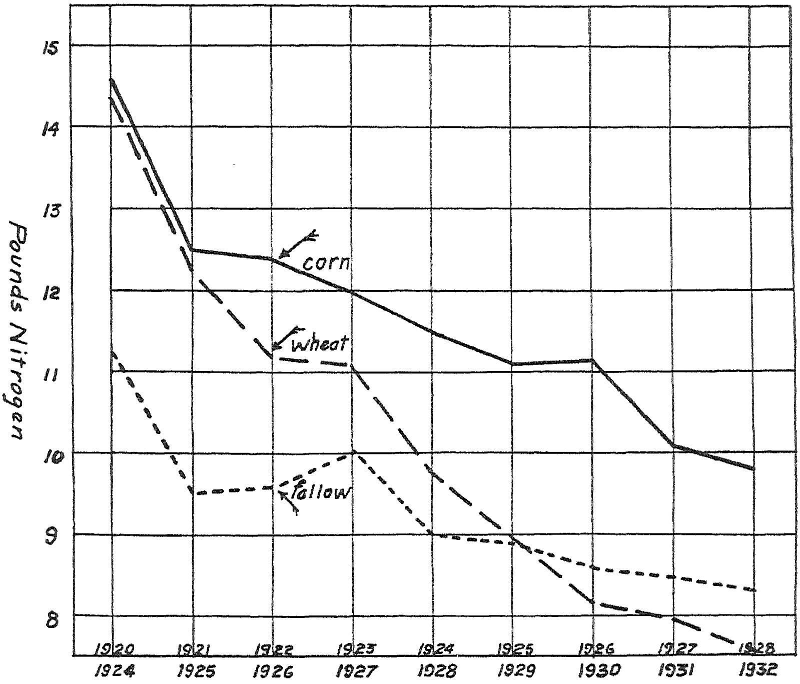

FIG. 4.—Nitrate nitrogen in the soil under different crops by advancing 5-year monthly averages from 1920–32, inclusive.

The decline in nitrate levels in the soil of these three plats can be measured more effectively by using the average figure of pounds of nitrate nitrogen per month during five successive years and averaging the 8 months for the growing season of March to October, inclusive. Such growing season and monthly averages per advancing 5-year periods are exhibited in graphic form in Fig. 4.

It is clearly evident that the nitrate levels fell faster with increasing years under wheat than under corn. This decline is very marked, however, under both crops. The nitrate levels under these two crops, starting together at about the equivalent of 15 pounds of nitrogen for the first 5-year monthly average, dropped to the final average of about 10 pounds under corn and to almost 7½ pounds under wheat. The corn plat represented a decrease of about 5 pounds, or 33%, while the corresponding figure under wheat was 7½ pounds, or 50%. On the fallow soil, the nitrate level was much lower at the outset on account of the disturbed nitrogen-carbon ratio following the application of the straw. Even with the early low nitrate, this soil shows a falling nitrate level in the absence of a crop. This decline is marked during the latter part of the period, which occurred in spite of the addition of the equivalent of 2 tons of green manure annually during the last 7 years. This addition seems to manifest some effects as shown by an irregularity in the form of a rise in the curve for the two 5-year periods of 1922–26 and 1923–27, which include the first years after 1926 when this green manure treatment was begun.

CLOVER STAND REFLECTS DECLINE IN FERTILITY

At the close of the nitrate study the plats were seeded to a mixture of red and sweet clovers drilled with light applications of limestone combined with fertilizer treatments. The first year stands (October 1933) of these legumes on the different plats reflect the declines in fertility represented by the nitrate levels according to the stand counts of the clovers on these plats as areas 3½ feet square. On the several wheat plats the stand count average is 40 plants, on the corn plats 55, and on the fallow plats 51. These figures do not show the magnitude of the differences since they do not reveal the size of the plants. The total dry weights of the clover plants harvested from eight separate square foot areas on each of the particular plats reported herewith were as follows: On the corn plat 9.0 grams, on the wheat plat 2.9 grams, and on the fallow plat 28.8 grams.

SUMMARY

These data emphasize with significant force the lowering of the nitrate level with time and at rates varying with different crops. Further, they point out that this decline is little disturbed by common fertilizer applications and continues under fallow even in the face of relatively heavy applications of green manure.

The data suggest that much nitrate production is going on at the expense of the virgin organic matter in the soil. Such changes in fertility levels reflect themselves in variable clover stands and in the crops following, suggesting that other fertility factors besides nitrogen may be following a similar decline and may be associated with the causes in operation.

ORGANIC BASE EXCHANGE COMPOUNDS IN SOILS[1]

W. T. McGeorge[2]

The term base exchange as applied to soils refers to the reaction between the base of a salt solution and the absorbing fraction of the soil in which the base of the latter is replaced in chemically equivalent amounts. At first the base exchange property of soils was viewed by many soil workers as a more or less constant or non-variable value and as the property of a limited group of alumino-silicates. While it was recognized that soil humus was an active absorbent, its quantitative exchange value lacked verification. As one outgrowth of the extensive research on the exchange property of inorganic materials by a large group of soil workers, several compounds were found to be involved and a dynamic rather than a static property was established. Probably because the term humus applied to a group of organic compounds rather than to any definitely defined substances, work upon the exchange property of organic matter, in most part, awaited progress with the inorganic compounds. It is only within the last few years that much has been contributed to our knowledge of the organic exchange compounds, but already this soil fraction has been shown to be equally important to the inorganic fraction and to contribute additional proof of the dynamic nature of this soil property.

During previous investigations in this laboratory (4, 5, 6),[3] it has been shown that the exchange capacity of organic matter and highly organic soils is a linear function of the percentage of carbon which they contain; that the exchange property of organic matter is in largest part due to ligneous compounds; that lignin definitely possesses a chemically equivalent exchange property; that the exchange capacity of organic matter is a linear function of the percentage of lignin; and that green manure has an exchange capacity which also is largely a function of its lignin content. While the exchange capacity of the inorganic soil colloids can be altered by physical and chemical methods, the organic exchange compound is subject to alteration by chemical and biological agencies. As for lignin itself, investigations have shown (4, 5) that the exchange capacity depends upon the method used in preparing or separating it from the mother substance, and that after preparation, it may be subject to further increase in exchange capacity by hydrolysis or fractionation. The highest exchange capacity obtained for ligneous material was approximately 400 M. E. per 100 grams. The part which biological agents play in the exchange capacity of organic matter was shown by the increase which accompanies its decomposition.

The above observations have been confirmed by Mitchell (7), Powers (9), and Muller (8), while Waksman and Iyer (11) believe that a protein linkage is in most part responsible for the exchange property of ligneous material.

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[1] Contribution from the Department of Agricultural Chemistry and Soils, Arizona Agricultural Experiment Station, Tucson, Ariz. Received for publication November 25, 1933.

[2] Agricultural Chemist.

[3] Figures in parenthesis refer to "Literature Cited," p. 579.

The principal sources of organic matter in soils are crop residues, weeds, green manure, and animal manure. While roots are rarely mentioned, it is nevertheless a fact that they do add many tons of organic matter to soils. Thorne (10) has stated that the root growth obtained by chemical fertilization furnishes all the organic matter required for bacterial functioning. To what extent do green manure and crop residues contribute to the exchange capacity of soils and can they be used to build up this capacity? Lignin is extremely resistant to the bacterial reactions associated with organic decomposition in soils which suggests that the incorporation of organic matter should materially enhance the exchange capacity. It is of additional interest that the unsaturated organic complex is far more stable than the inorganic exchange complex.

EXPERIMENTAL

EXCHANGE CAPACITY OF PLANT MATERIALS

A number of plants which are used as green manure and which contribute crop residues to soils were selected and grown in silica sand or water cultures. This procedure was followed in order to avoid contamination from soil colloids. The plants selected were corn, cowpeas, rye, wheat, oats, and alfalfa. The period of growth was 3 weeks at the end of which time the entire plants were removed, dried, and roots and tops thoroughly ground separately. A preliminary experiment was conducted with extreme care, as follows: 1-gram portions of wheat roots were leached with neutral $NH_4C_2H_3O_2$ until the leachings were neutral, then leached with 80% alcohol until free of $NH_4C_2H_3O_2$ and finally with normal $BaCl_2$ solution. Ammonium was determined in the $BaCl_2$ leachate, after which they were leached with water until free of $BaCl_2$, then with NH_4Cl solution, and Ba determined in this leachate. These operations were repeated several times to assure the chemical equivalency of the reaction. The exchange capacity thus obtained is given in Table 1.

TABLE 1.—*Exchange capacity of three samples of wheat roots as M. E. per gram of dry matter.*

Sample No.	NH_4 absorbed	Ba absorbed
1	0.099	0.099
2	0.130	0.132
3	0.134	0.133

These data show conclusively that root material exhibits the property of base exchange in chemically equivalent proportions and thus acts similar to the above-ground part of the plant (6).

The entire group of materials was then subjected to similar leachings with neutral 0.1 normal solutions of $Ba(C_2H_3O_2)_2$ and $NH_4C_2H_3O_2$. and the exchange capacities given in Table 2 were found.

TABLE 2.—*Exchange capacity of roots and tops of several plants commonly contributing to the organic supply of soils in M. E. per gram of dry matter.*

Plant	Exchange capacity, roots	Exchange capacity, tops
Corn	0.173	0.285
Cowpeas	0.300	0.379
Rye	0.210	0.260
Wheat	0.128	0.183
Oats	0.198	0.240

All these materials show exchange capacities equivalent to that of many soils and it is evident that as crop residues they should increase this capacity of soils.

NATURE OF EXCHANGE COMPOUNDS IN PLANTS

Previous investigations (5) have shown that lignin is the principal organic compound contributing to the exchange reaction of plant material, but from the standpoint of green manuring it appeared of interest to learn whether inorganic compounds, the so-called mineral portion of plants, contributed to their exchange capacity. Organic exchange compounds can be destroyed without injury to the inorganic exchange complex, either by ashing at 350°C or by digestion with H_2O_2 (2, 3). The plant materials used in the preceding experiment were ashed by heating for 8 hours in an electric muffle at 350°C. The equivalency and capacity of the exchange property of this ash was determined by the same methods used for the dry plant material and the results given in Table 3 were obtained.

TABLE 3.—*Exchange capacity of the ash obtained by heating plant materials to 350°C expressed as M. E. per gram of original dry (unashed) material.*

Plants	Exchange capacity, ash of roots	Exchange capacity, ash of tops
Corn	0.040	0.096
Cowpeas	0.090	0.049
Rye	0.174	0.164
Wheat	0.106	0.134
Wheat	0.089	——
Alfalfa	——	0.047
Oats	0.170	0.174

These data show that plant materials or plant residues contain both organic and inorganic compounds which possess the property of base exchange. They indicate that for corn, and cowpeas the exchange property is in largest part a function of organic matter, while for the small grain crops, such as wheat, oats, and rye, it is in largest part due to inorganic compounds.

A sample of plant ash was submitted to the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture for X-ray examination and was found to contain only silica and calcite crystals,[4] the remainder being made up of amorphous material. Since the exchange compounds represented by montmorillonite and halloysite are crystaline and since the synthetic zeolites and iso-electric precipitates are non-crystalline and show no diffraction pattern, it appears that the inorganic exchange compounds of plants are similar to the latter. Plants probably possess the property of synthesizing exchange compounds, a reaction which has been found to occur in alkali soils (1).

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[4] The author is indebted to Dr. S. B. Hendricks, Bureau Chemistry and Soils, U. S. Dept. of Agriculture, for the X-ray examination of this material.

Further evidence of this was obtained by grinding the materials in a ball mill for 72 hours. The exchange capacity of wheat roots, alfalfa tops, and peat, before and after grinding are given in Table 4.

TABLE 4.—*The effect of grinding upon exchange capacity of organic matter expressed as M. E. per gram of dry matter.*

Sample	Before grinding	After grinding
Wheat roots..........	0.157	0.150
Alfalfa tops...........	0.230	0.244
Peat.................	0.650	0.720

These data show that the exchange capacity of organic matter is not altered by grinding the material to a finer state of division. Since the exchange capacity of crystalline colloids is increased by grinding and that of synthetic zeolites and iso-electric precipitates is not increased, this experiment offers further data as to the nature of the compounds in plant material.

DISCUSSION

Soil organic matter is essentially a transient soil constituent. To a certain extent the changes taking place tend to balance one another, depending upon the raw plant material which becomes incorporated with the soil and the activity of the organisms decomposing it. Sugars and starch are rapidly consumed by soil organisms because they serve as a source of energy. Nitrogenous compounds, notably the proteins, also decompose with comparative rapidity but are maintained or even increased by the micro-flora. Lignin and the cellulose compounds are decomposed very slowly and therefore represent practically all the original plant material which contributes to soil humus.

Organic matter, both of itself and through its chemical and biological decomposition in soils, is of fundamental importance to soil fertility. In addition to acting as a source of energy for the micro-flora, it makes for a better mechanical state, increases the water-holding capacity, improves plant food availability, and, in alkali soils, acts as a valuable source of carbon dioxide. In fact, throughout the entire root zone, an environment favoring the foraging activities of roots is created.

Green manure and crop residues have not received deserved recognition for their contribution to the base exchange property and capacity of soils. This is especially true of roots which annually add many tons of organic matter to soils which is thoroughly distributed throughout the soil. Ligneous material is the most important organic material possessing the exchange property (4, 5) as shown by its linear relation to the exchange capacity of organic matter and highly organic soils. It is of interest that a base exchange property may be imparted to cellulose (5) by digestion with acids which suggests that the cellulose compounds probably also contribute exchange properties to the soil. Since these two substances represent the fraction of organic matter which is most resistant to bacterial decomposition, it is self-evident that green manure and crop residues should contribute much to the dynamic state of the exchange complex of soils.

SUMMARY

Green manures and crop residues, which include plant roots, materially enhance the exchange capacity of soils.

An inorganic or mineral fraction of plant material also possesses the property of base exchange.

Whether of the nature of isoelectric precipitates or synthetic zeolites, the bases adsorbed by the inorganic fraction of this exchange complex, as well as those adsorbed by the organic fraction, should be in an easily available form because of their non-crystalline structure.

LITERATURE CITED

1. BURGESS, P. S., and McGEORGE, W. T. Zeolite formation and base exchange reactions in soils. Ariz. Agr. Exp. Sta. Tech. Bul. 15. 1927.
2. KELLEY, W. P., DORE, W. H., and BROWN, S. M. The nature of the base exchange material of bentonite, soils and zeolites as revealed by chemical investigation and X-ray analysis. Soil Science, 29:25–45. 1931.
3. KERR, H. W. The nature of base exchange and soil acidity. Jour. Amer. Soc. Agron., 20:309–335. 1926.
4. McGEORGE, W. T. The base exchange property of organic matter in soils. Ariz. Agr. Exp. Sta. Tech. Bul. 30. 1930.
5. ———. Organic compounds associated with base exchange reactions in soils. Ariz. Agr. Exp. Sta. Tech. Bul. 31. 1931.
6. ———. Chemical equivalent base exchange reactions in plants. Plant Physiol., 7:119–124. 1932.
7. MITCHELL, J. The origin, nature, and importance of soil organic constituents having base exchange properties. Jour. Amer. Soc. Agron., 24:254–275. 1932.
8. MULLER, J. F. Some observations on base exchange in organic materials. Soil Science, 35:229–237. 1933.
9. POWERS, W. L. Characteristics of dispersable organic colloids in peats. Jour. Agr. Res., 44:97–111. 1932.
10. THORNE, C. E. The function of organic matter in the soil. Jour. Amer. Soc. Agron., 18:767–793. 1926.
11. WAKSMAN, S. A., and IYER, K. R. N. Contributions to our knowledge of the chemical nature and origin of humus; III The base exchange capacity of "synthesized humus" (ligno-protein) and of natural humus complexes. Soil Science, 36:57–67. 1933.

THE WHEAT MEAL TEST FOR EVALUATING THE QUALITIES OF SMALL SAMPLES OF WHEAT[1]

H. K. WILSON AND M. C. MARKLEY[2]

One of the greatest problems confronting the plant breeder is that of the time required to evaluate his creations adequately. Especially is this true in the case of wheat where several years must elapse before sufficient seed is available for making the standard milling and baking tests. A simple test of baking quality using only a small quantity of seed would permit the elimination of numerous lines in the early years of a breeding program.

The writers became interested in the simple test for small quantities of wheat as outlined by Pelshenke (5)[3] and by Cutler and Worzella (1, 2). These investigators have followed the principles of the so-called Saunders' test (6). In this test the resistance of a fermenting dough ball in water to hydrolytic disintegration is considered to be positively correlated with baking strength. Instead of using flour as did Saunders, Cutler and Worzella ground whole wheat to a medium degree of fineness, while Pelshenke ground wheat in such a manner as to reduce the endosperm to essentially the fineness of flour.

EXPERIMENTAL METHODS

The methods outlined by Cutler and Worzella were followed closely. Single grindings on each of two mills were made for each sample. Triplicate dough ball tests were made on each ground sample. In the discussion of errors of the method, variability in grinding the samples is not included in the computed errors but is included in the portion of the variability due to varietal factors.

Preliminary tests showed definite differences between durum, winter, and spring wheats and further investigations were outlined to test the accuracy of the method for differentiating varieties within a class.

Thirty-nine varieties of hard red spring wheat and 17 varieties of hard red winter wheat of the 1931 crop were studied. The spring wheat samples were taken from a composite mixture of seed from rod rows grown at University Farm, Waseca, Morris, and Crookston, Minn. The winter wheat samples were mixtures of seed from rod row trials grown at University Farm and at Waseca.

Two types of mills were employed in the investigations. The Wiley mill, fitted with a 1-mm sieve, gave a relatively uniform product, but the use of this mill is time consuming, so in order to determine if a quicker grinding process could be used, portions of the same lots of wheat were ground on a power-driven Arcade burr mill. After passing the wheat through the burrs the chop was sifted by hand on a 1-mm sieve. The scalpings were reground, fines sifted out, and the scalpings again ground and mixed with the other ground fractions. Despite the fact that this method required six distinct operations, it was found to be appreciably faster than grinding thru the Wiley mill.

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[2] Associate Agronomist and Instructor, respectively.

[3] Numbers in parenthesis refer to "Literature Cited," p. 586.

The cost of installation of a power-driven mill of the Arcade type is substantially less than that of a complete Wiley mill installation.

Milling and baking trials were made of the wheats studied. These investigations form a part of the regular studies in wheat improvement as conducted jointly by the Divisions of Agronomy and Plant Genetics and Agricultural Biochemistry of the Minnesota Agricultural Experiment Station. The baking method used was the high diastatic modification of the basic baking method of the A. A. C. C., as reported by Markley and Bailey (4).

Loaf type as used in this paper refers to the smoothness and regularity of the external appearance of the baked loaf. A loaf having a smooth, symmetrical exterior was given a perfect score of 10. A smooth break was scored 8–9; a rough break 6–7; a shell top 4–5; and a torn or broken exterior was graded 0-4.

Baking strength scores were calculated as follows: 0.2 (loaf volume — 300) + 2 (grain — 90) + (texture — 90).

RESULTS

SPRING WHEAT

The results secured in tests of meal from 39 varieties of spring wheat ground by the Arcade and by the Wiley mills are compared with the results from milling and baking trials in Table 1.

In order to check the significance of the results presented in Table 1, the data were analyzed according to Fisher's (3) analysis of variance method (Table 2). As two mills were used, the analysis is presented for each.

In Fisher's table of 1% points for the distribution of Z with N_1 = 24 and N_2 = 60, the points most nearly approaching the corresponding values in this analysis, the value of Z = .3746. As the value obtained was 1.7091 for the Arcade mill and 1.2400 for the Wiley mill, the varieties differed significantly in the time required for the disintegration of the dough balls. The correlation between the Wiley and the Arcade mills for the time test as applied to spring wheats was 0.6387.

Since differences were exhibited between varieties, the next step was to determine the relationships to actual milling and baking studies as performed regularly by the Agricultural Biochemistry Division on the promising wheats developed by the Agronomy and Plant Genetics Division of the University of Minnesota. The percentages of protein, loaf volumes of baked bread, loaf type, and the strength scores which are measures of milling and baking value were correlated with the time tests. The results, as previously reported by the authors (7), are given in Table 3.

According to the correlation coefficients, time was not significantly correlated with protein percentage or loaf type. However, time was correlated with loaf volume and strength score for meal ground by both the Wiley and the Arcade mills, exceeding the 5% point in each

TABLE 1.—*Average number of minutes required for the disintegration of dough balls from meal ground by the Wiley and Arcade mills, protein percentage, loaf volume, and baking strength score of hard red spring wheats.*

Variety	Nursery or Minn. No.	Disintegration minutes		Protein %	Loaf volume, cc.	Strength score
		Arcade	Wiley			
Marquis	Acc. 1239	290	—	17.4	502	63
Marquillo	2202	197	258	18.0	420	42
Ceres	Acc. 2223	284	347	16.8	570	74
North Dakota 1656		268	335	17.2	550	66
North Dakota 1656–44		232	323	17.0	570	78
North Dakota 1656–109		276	358	18.0	670	89
Hope	Acc. 2297	296	354	17.2	430	44
H–44	Acc. 2301	281	377	17.3	477	56
Marquis x Kanred	II–17–40	126	306	17.1	472	53
Double Cross	II–21–80	222	319	17.1	447	48
Double Cross	II–21–85	265	275	17.2	425	48
Double Cross	II–21–86	253	286	17.3	492	61
Double Cross	II–21–97	305	417	16.9	470	56
Double Cross	II–21–98	265	361	17.2	585	77
Double Cross	II–21–99	275	274	16.8	442	49
Double Cross	II–21–100	233	294	17.6	537	69
Double Cross	II–21–102	268	300	17.7	542	74
Double Cross	II–21–103	291	359	17.7	532	72
Double Cross	II–21–104	—	320	16.9	502	64
Double Cross	II–21–105	288	391	17.8	480	55
Double Cross	II–23–33	269	316	17.0	500	61
Double Cross	II–23–34	282	370	17.4	610	81
Double Cross	II–23–36	261	342	17.7	580	77
Double Cross	II–23–37	269	418	17.2	590	79
Marquillo x Red Bobs	II–22–49	254	382	17.5	475	56
Minturki x Marquis	II–22–61	165	305	18.1	412	40
Minturki x Marquis	II–22–65	206	339	17.3	437	52
Marquis x H–44	II–24–33	192	330	17.2	417	44
Marquis x H–44	II–24–35	194	282	18.3	425	49
H–44 x Marquis	III–29–4	254	353	17.9	400	44
H–44 x Marquis	III–29–9	327	477	17.5	500	65
H–44 x Marquis	III–29–10	258	344	16.7	510	66
H–44 x Marquis	II–26–6	317	397	16.3	470	59
Pentad x Marquis	III–29–12	302	366	16.7	447	50
Reliance x Hope	Acc. 2325	224	279	16.1	442	52
Reliance x Hope	Acc. 2326	200	279	16.6	465	57
Ceres x Hope	III–31–1	161	214	16.6	380	36
Ceres x Hope	III–31–2	241	353	16.9	515	70
Ceres x Hope	III–31–3	320	313	17.0	517	75
Mean		252	335			

case. On the basis of the 1 year's trials, this indicates that the time test has possibilities when used in evaluating probable milling and baking quality of small samples of hard red spring wheat.

WINTER WHEAT

The results for the 17 lines of winter wheat ground and tested by the same methods used for spring wheat are given in Table 4.

TABLE 2.—*Analysis of the variance of time of disintegration of dough balls made from spring wheats.*

Variation	Degrees of freedom	Sums of squares	Mean squares	Value of Z	Standard error of mean of 3 tests in %
		Arcade Mill			
Between varieties...	37	241,617	6,530		
Within varieties or error............	76	16,295	214	1.7091	3.3
Total...........	113	257,912			
		Wiley Mill			
Between varieties...	37	265,841	7,185		
Within varieties or error............	76	45,709	601		
Total...........	113	311,550		1.2400	4.2

TABLE 3.—*Correlation coefficients obtained between various baking characteristics and the wheat-meal fermentation time test of 37 spring wheat varieties.*

Mill used	Correlation between "time" and					
	Protein %	Loaf volume, cc	Loaf type	Strength score	5% point	2% point
Arcade....	—.0102	.4002	.0539	.4552	.3246	.3810
Wiley.....	.0021	.3712	.0145	.3758	.3246	.3810

TABLE 4.—*Minutes required for the disintegration of dough balls from meal ground by the Wiley and Arcade mills, protein percentage, loaf volume, and baking strength score of red winter wheats.*

Variety	Disintegration minutes		Protein %	Loaf volume, cc	Strength score
	Arcade	Wiley			
Minturki 1507...............	129	256	14.5	380	31
Minhardi 1505...............	76	72	14.7	312	17
Minard 2199.................	73	51	13.4	385	34
Minhardi x Minturki II–19–7...	210	236	15.4	437	46
Minard x Minhardi II–20–6....	354	397	13.7	407	38
Minard x Minhardi II–20–20...	76	72	14.2	420	34
Kanred x Minhardi C.I. 8042...	128	232	14.5	422	45
Eureka x Minhardi C.I. 8036...	69	37	14.8	365	21
Minturki x Marquis II–22–7...	108	183	14.7	400	38
Minturki x Marquis II–22–38..	109	191	15.0	390	37
Minturki x Marquis II–22–39..	269	334	14.3	392	36
Minturki x Marquis II–22–50..	140	240	14.0	402	38
Minturki x Marquis II–22–75..	257	332	14.5	400	38
Minhardi x Marquis II–22–17..	208	328	14.6	395	38
Minhardi x Marquis II–22–24..	150	244	14.2	447	48
Minhardi x Marquis II–22–25..	136	278	13.8	407	40
Minhardi x Marquis II–22–60..	182	242	13.7	417	30
Mean................	157	219			

As in the case of the spring wheat samples, time in making the test was less when the Arcade mill was used. For an average of the 18 samples, 157 minutes were required for the disintegration of the dough ball from the meal ground by the Arcade mill and 219 minutes when the Wiley mill was used. It is evident that considerably less time was required to complete tests with winter than with spring wheats. Also, differences were large, as shown in Table 4. For the Wiley mill the variety Eureka x Minhardi, C. I. 8036, gave a time test of 37 minutes, while Minard x Minhardi II–20–6 required 397 minutes for dough ball disintegration, a difference of 360 minutes.

The correlation between the time of disintegration of dough balls from winter wheat ground by the Wiley and the Arcade mills was .8773, indicating that the Arcade mill might be suitable for grinding the wheat.

The winter wheat results given in Table 4 were analyzed as for spring wheat. The calculations are presented for both mills in Table 5.

TABLE 5.—*Analysis of variance in time of disintegration of dough balls made from winter wheats*

Variation	Degrees of freedom	Sums of squares	Mean squares	Value of Z	Standard error of mean of 3 tests in %
		Arcade Mill			
Between varieties...	16	305,298	19,081		
Within varieties or error............	34	6,655	277	2.1062	6.1
Total.........	50				
		Wiley Mill			
Between varieties...	16	527,716	32,982		
Within varieties or error............	34	27,973	823	1.8454	7.6
Total.........	50	555,689			

The calculated value of Z for the above determination of the time of disintegration in which $N_1 = 16$ and $N_2 = 34$ is determined. In Fisher's table of 1% points for the distribution of Z with $N_1 = 12$ and $N_2 = 30$, the points most nearly approaching the corresponding values in this analysis, the value of $Z = .5224$. The computed value of Z was 2.1062 for the Arcade mill and 1.8454 for the Wiley mill.

As with the spring wheats, simple correlation coefficients between the milling and baking data and the time tests were computed. These are presented in Table 6.

Coefficients of correlation between the time test and milling and baking factors were of nearly the same size for winter as for spring wheats. Because of the smaller numbers included in the winter wheat trials, the correlations do not reach the same levels of significance as measured by Fisher's test (3).

There were no significant relationships between the time test and the protein percentages, loaf type, or loaf volume with either mill.

TABLE 6.—*Correlation coefficients obtained between various baking characteristics and the wheat-meal fermentation time test of 17 winter wheat varieties.*

Mill used	Correlation between "time" and					
	Protein	Loaf volume	Loaf type	Strength score	5% point	2% point
Arcade....	—.1215	.3196	—.0909	.3721	.4821	.5577
Wiley.....	—.1044	.4089	.1291	.5421	.4821	.5577

The variability in protein content in each of these series of wheat was very low. It may be entirely possible that in a series of wheat samples having a greater variability in protein content there might be a significant correlation between protein content and time of disintegration of its dough ball. For the Wiley mill, as with spring wheat, the correlation between the time test and strength score exceeded the 2% point. The correlations were higher for the Wiley than for the Arcade mill.

When the individual data for the winter wheats are studied in relation to the time test, there are many inconsistencies. Using the Wiley mill as the standard for comparison, the variety Minard x Minhardi II–20–6 was highest in the time test with a score of 397 minutes. On the basis of odds of 45 to 1, any variety with a time test of 350 minutes was lower than II–20–6. On this basis, every other variety was lower in the time test than II–20–6. Two of these varieties were superior to II–20–6 in baking strength score.

The data in Table 4 indicate a much greater range in the winter wheats than was true for the spring sorts tested. The winter lines probably represent a group of much greater differences in time of disintegration of dough balls than is true of the spring wheats included.

SUMMARY AND CONCLUSIONS

The wheat-meal fermentation time test as outlined by Cutler and Worzella (1, 2) was applied to 39 varieties of spring wheat and 17 varieties of winter wheat. This test appeared to have possibilities on the basis of the limited trials.

Varieties of winter and spring wheat exhibited significant differences. Wider differences were shown by the winter wheat varieties than by the spring wheats.

Spring wheat tests exhibited a positive correlation between time of dough ball disintegration and loaf volume and baking strength score as determined by the milling and baking trials. Winter wheat time tests were positively correlated with strength score when the Wiley Mill was used to grind the samples.

Spring wheat varieties included in the trials constituted a highly selected group and this probably was an important reason for a narrower range of difference in the number of minutes required for dough ball disintegration than was apparent for the winter sorts.

Definite conclusions as to the value of the Arcade mill as a substitute for the Wiley mill cannot be drawn from the present data.

LITERATURE CITED

1. CUTLER, G. H., and WORZELLA, W. W. A modification of the Saunders test for measuring "quality" of wheats for different purposes. Jour. Amer. Soc. Agron., 23 : 1000–1009. 1931.
2. ———, ———. The wheat-meal fermentation time test of "quality" in wheat as adapted for small plant breeding samples. Cereal Chem., 10 : 250–262. 1933.
3. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 3. 1930.
4. MARKLEY, M. C., and BAILEY, C. H. A supplementary procedure with the basic baking test for use with low diastatic flours. Cereal Chem., 8 : 300–305. 1931.
5. PELSHENKE, P. Beiträge zur bestimmung der backfähizkeit von weizen und weizenmehlen. Archiv. für Pflanzenbau, 5 : 108–151. 1930.
6. SAUNDERS, H. A., and Humphries, S. The Saunders test. Jour. Inst. Agr. Bot., 2 : 1. 1928.
7. WILSON, H. K., MARKLEY, M. C., and BAILEY, C. H. The wheat-meal fermentation time test. Cereal Chem. In Press.

SOIL FACTORS IN THE FAILURE OF LODGE POLE PINE PLANTINGS[1]

T. J. DUNNEWALD[2]

Attempts at replanting the treeless areas of smaller size in the forest reserves around Laramie, Wyoming, with various species of pine have met with varying degrees of success. Formerly timbered areas, moist north slopes, and aspen groves have been generally successful. Old grassed slopes, windy and shallow slopes, and sage brush land have shown many failures. In some cases, failure is evident the first year, while in other cases plantings 4 or 5 years old thin out and die.

Chemical analysis of soil samples seems to give little evidence as to whether the cause of failure is soil deficiency or diseases or due to physical conditions, such as moisture and temperature variations. Examination of some of the failures in the Pole Mountain District suggested that in some cases the soil was too gravelly, shallow, and exposed to heavy winds and drying out. In other cases, diseased conditions on nearby aspen groves suggested the possible prevalence of soil- or wind-borne disease. In other cases, the cause seemed obscure and no suggestion was offered by examination of the site.

With the help of Fred Miller, Junior Forester, bulk samples of soil from four sites were collected. Plantings had succeeded on two of the sites and failures had occurred on the other two. The soil was collected to a depth of 6 to 8 inches, brought to the greenhouse in boxes, mixed, put through a ¼-inch mesh sieve, and placed on the greenhouse bench. Half of each soil was sterilized for 24 hours with live steam before being placed in a separate compartment on the bench. The four soils and the sites from which they were collected are as follows:

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[2] Assistant in Soil Investigation.

Site I.—Dark brown loam in aspen grove, high slope on east side of Canyon. Soil moist with a thick cover of leaves and organic matter (partly decomposed). First planting of limber pine succeeded. Well covered with snow. Good drainage.

Site II.—Yellowish (to pink) brown loam, rather compact heavy soil washed into the canyon bottom flat. Plowed and used for nursery. All plantings have succeeded—no noticeable disease. Fair organic matter; good moisture and drainage conditions.

Site III.—Brown gravelly loam to gravelly clay loam. Residual soil on high granite slope. Slope faces west, covered with thin grass and sage cover on shallow stony soil. Fair organic matter and poor moisture conditions. Bare and no snow accumulation. Plantings of yellow pine failed. May have been due to weak stock or to drying out or shallow soil.

Site IV.—Light brown to reddish brown loam to very fine sandy loam 18 to 24 inches deep on reddish quartzite sandstone and limestone. High sage and grass slope faces west. Good drainage; fair moisture and organic matter. Fenced in area south of Summit Inn. Two plantings of limber and yellow pine failed. Scrubby aspen grove a few rods down the slope.

The screened soils were packed into compartments or boxes 12 by 18 inches in size. The soil was about 6 inches deep. Two hundred lodge pole pine seeds were planted in each box, covered with 1/8 inch of fine soil which was gently pressed down on the seed and watered. The whole was covered with paper and after 12 days daily counts of the seedlings in each box were made.

CHEMICAL AND PHYSICAL CHARACTER OF SOILS

Various tests were made to bring out the characteristics of the four soils, and the results shown in Table 1.

TABLE 1.—*Chemical and physical soil tests.*

Soil	Available P, p.p.m.	pH	Soluble salts %	Free $CaCO_3$ %	Hygroscopic moisture %	Loss with H_2O_2 %	Additional loss on ignition %	Sands %	Silt and clay %
Aspen...	10	6.7	0.000	0.000	1.05	1.21	7.63	88.6	11.4
Nursery.	15	6.7	0.016	0.178	0.84	0.78	4.06	86.06	13.94
Granite..	10	6.5	0.001	0.060	1.03	0.87	7.29	91.97	8.13
Quartzite summit.	14	6.7	0.005	0.178	1.01	1.41	7.17	88.58	11.42

The soils are all slightly acid in reaction with practically no soluble salts or free calcium carbonate. The available phosphorus is low compared to cultivated soils; it is higher in the aspen and quartzite soils than in the other two. The aspen and quartzite soils have the most humus and organic matter, while the nursery soil dries out to the greatest extent upon exposure to air. The nursery soil has the most clay and silt and the granite soil the least. The soils are all of the sandy loam group with but small variations in physical make-up. The granite soil is noticeably gravelly and sandy and the nursery soil packs harder than the others and has slightly more clay. The aspen soil remains loose and friable when watered and pressed because of its higher content of humus and unhumified organic leaf mold and trash.

GERMINATION OF LODGE POLE PINE SEEDS

The lodge pole pine seeds were collected in Pike National Forest in 1928 at an elevation of 8,500 feet and artificially extracted. A germination test in September 1930 gave 59%; in May 1932, 48%; and in March 1933, 55% (after 10 days). The arrangement of the soil plats in the greenhouse was as follows:

Sterilized Soil			
1	2	3	4
Unsterilized Soil			
Aspen soil	Nursery soil	Granite soil	Quartzite soil

Successful Plantings Plantings Failed

While most of the seeds germinated in 6 days in the germinator, they did not appear until 8 to 10 days in the soil. Counts were begun on the twelfth day and new plants continued to appear for 25 to 30 days.

PESTS

Immediately upon the appearance of the young seedlings, three types of pests appeared. Small black ants dug holes along side some plants and these soon wilted and died. The ants were finally eliminated. Small sow-bugs appeared and burrowed in the soil. At night or when the plantings were darkened and covered with paper, these pests chewed and cut off the tops and stems of some of the seedlings above ground. Later, a mold or fungus appeared which attacked the roots and stems of some of the plants causing them to curl up or wilt and topple over on the ground. Brown spots appeared on the affected stems and roots, while plants transferred to sterile media produced colonies of a white mold. The mold appeared at first only in the sterilized boxes, but toward the end of the 25-day period a few wilted plants appeared also in the untreated soils. Leaving the boxes open and exposed to light seemed to hold the sow-bugs and mold in check to some extent. No preventive spraying was attempted.

Whether these pests were brought in with the soil or whether they migrated from surrounding soils (in the greenhouse) is not positively known, but it is believed that a part or perhaps all of them originated in the soil as brought in from the forest. Sterilizing seemed to stimulate the activity of the mold in all of the soils. The available phosphorus was increased, but the reaction of the soils was not permanently affected by the steam treatment.

GERMINATION RECORD

Table 2 and Fig. 1 show the germination of the seeds. The aspen soil seems to be ideal for the germination and growth of lodge pole seedlings. Germination was most rapid and after 23 days reached the maximum for the laboratory germinator. Its loose but moist condition due to its high organic matter content doubtless explains the favorable result obtained with this soil. The granite soil showed slight evidence of soluble salts and packed slightly harder, factors which may explain its position in second place.

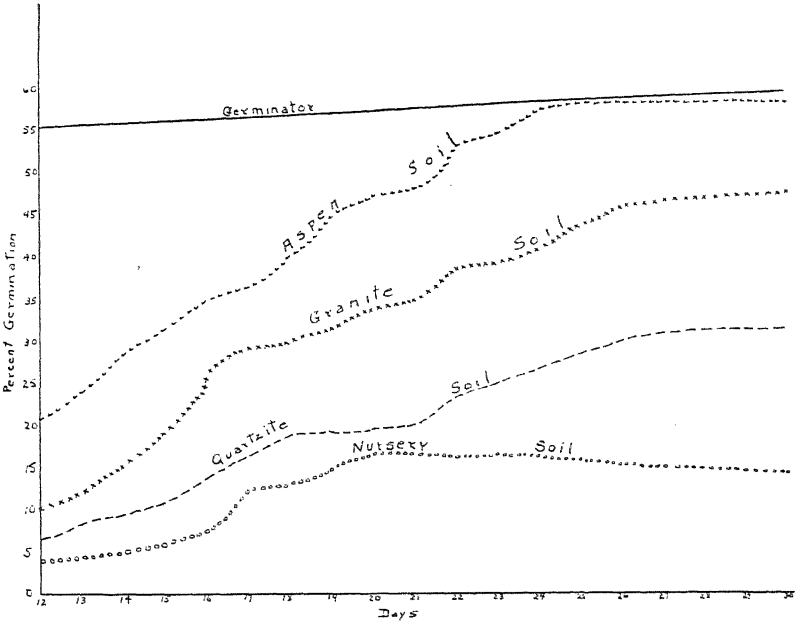

FIG. 1.—Germination of lodgepole pines on four soils, Pole Mountain Reserve, Wyoming, March 18 to April 18, 1933.

Germination was much slower and less complete on the quartzite and nursery soils. These soils also packed harder and water and air penetrated less readily. More leaves and partly decomposed leaf mold would perhaps make these soils more loose and penetrable. Proper admixture of organic matter would perhaps make these soils equal to the aspen soil in ability to grow lodge pole pine. The dark color of the aspen soil also may cause it to absorb more of the sun's heat and to dry out less readily, which may also be important factors.

TABLE 2.—*Lodge pole pine seed germination, 200 seeds planted in each plat March 18, 1933.*

Date	Plat No. 1, aspen soil	Plat No. 2, nursery soil	Plat No. 3, granite soil	Plat No. 4, quartzite soil
		Sterilized soil		
Mar. 30	31	28	22	24
31	39	34	23	27
Apr. 1	48	38	27	29
2	50	37	28–4 wilt	27
3	51	44	33	35
4	55	48	34	35
5	49–6 wilt	47–1 wilt	32–2 wilt	33–2 wilt
6	56–4 wilt	58	32	33
7	47–8 wilt	57–3 wilt	34–3 cut off	30–2 cut off
8	53	67–5 wilt	35–2 wilt	33
9	54	73–3 wilt	38–2 cut off 2 wilt	36–1 wilt
10	55–2 wilt	70–4 wilt	32–2 cut off 2 wilt	35–2 wilt
12	52–3 wilt	89–5 wilt	41–1 cut off	33–1 wilt 1 cut off
14	55–2 wilt	88–1 wilt	44–1 cut off	34
16	65–1 wilt	77–5 wilt 1 cut off	46–1 cut off 1 wilt	30–2 wilt
		Unsterilized Soil		
Mar. 30	42	6	18	12
31	48	9	24	16
Apr. 1	59	9	29	17
2	64	13	38	22
3	69	15	53	27
4	73	25	56	32
5	82	27	59	37
6	89	31	62	35–2 cut off
7	95	34–1 cut off	68	37–2 cut off
8	96	32–2 cut off	70–1 wilt	38
9	109	31–2 cut off 2 wilt	76–5 wilt	48–3 cut off
10	111	32–2 wilt	76–4 wilt 1 cut off	52–1 cut off
12	116	30–2 cut off	85–3 wilt	62–1 cut off
14	119	26	89–2 wilt	65–2 cut off
16	121	28	95–1 cut off 2 wilt	71–1 wilt 1 cut off

TABLE 3.—*Total germination on all soils (healthy plants).*

Soil	Unsterilized %	Sterilized %	Losses unsterilized %	Sterilized %
Aspen	55	28	0.0	10
Nursery	16	35	4.5	8
Granite	36	16	7.5	10
Quartzite	26	18	4.0	6.5

The loss due to wilt was 10% for the aspen soil, 8% for the nursery soil, 7% for the granite soil, and 2½% for the quartzite soil.

Sterilization was distinctly unfavorable to germination, although some other method of sterilizing might have given better results. The total germination on the sterilized and unsterilized soils on the twenty-third day is given in Table 3.

CONCLUSIONS

The evidence from the data to date indicates that when temperature and moisture conditions are regulated, the aspen soil gives 100% possible germination, the granite soil 65%, the quartzite soil 47%, and the nursery soil 29%.

The losses due to wilt or damping off amount to as much as 10% and to pests to as much as 5%. Differences in soil account for as much as 50% reduction in germination. Steam sterilizing encourages loss from mold and wilt rather than decreasing them.

THE EFFICIENCY OF CERTAIN AMMONIATED SUPERPHOSPHATES AND OTHER PHOSPHATE FERTILIZERS[1]

F. B. Smith, P. E. Brown, H. T. Miller, and C. C. Mensing[2]

The efficiency of different phosphate fertilizers has been much discussed ever since these fertilizers were first advocated for use. During the past 30 years, many investigators have given considerable attention to the economics of the use of different phosphate fertilizers, especially rock phosphate and superphosphate. The question of the relative value of these two phosphates has not been settled definitely, mainly because the efficiency of a fertilizer is affected by many physical, chemical, and biological soil factors.

The basis of most laboratory tests for the availability of the plant food constituents of fertilizers is the assumption that the materials dissolving in some particular solvent are available for plant use. Crop response to the fertilizer, however, has not always been correlated with the solubility of the constituents and various solvents have been employed in the attempt to obtain a definite correlation.

Since the earliest development of soil chemistry, it has been the hope of agricultural chemists to develop a simple, rapid test which would reveal the efficiency of different fertilizing materials without the necessity of time-consuming field experiments. As yet, however, there is no one method which will show accurately the efficiency of fertilizers when applied to different soil types.

The recent achievement of producing anhydrous ammonia cheaply has made it economically possible to place on the market a fertilizer known as ammoniated superphosphate. Before this product came into use as a fertilizer, the phosphate soluble in neutral ammonium citrate had been termed available by agricultural chemists, but greenhouse and field experiments show that this solvent will not serve for the determination of the availability of the phosphorus in ammoniated superphosphate.

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[1] Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Journal Paper No. B-78 of the Iowa Agricultural Experiment Station. Project No. 230. Received for publication December 18, 1933.

[2] Associate Professor, Head of Department, and Research Fellows, respectively.

The purpose of the work reported here was to determine the crop response to a number of phosphate fertilizers and to measure by various methods the available phosphorus in soils treated with these fertilizers.

EXPERIMENTAL

It is evident from a review of the literature that soil investigators are not in agreement upon the subject of the value of various phosphate fertilizers. The present work was planned to obtain more information regarding the efficiency of certain phosphate fertilizers. Several chemical and biological methods were used to determine the available phosphorus in the soil. Crop response to certain phosphate fertilizers on Carrington loam in the greenhouse was determined, using wheat as the crop.

A slightly acid Carrington loam was used. This particular soil had a relatively low total phosphorus content and had received no fertilizer treatment during the last several years. The soil was brought to the greenhouse and sieved through a one-fourth inch sieve.

Two experiments were conducted in the greenhouse to determine the crop response of this soil to the various fertilizers used and to measure the available phosphorus in the variously treated soils by several laboratory methods.

EXPERIMENT I

In the first experiment the soil was treated in 4-gallon earthenware pots in quadruplicate. Two pots of soil of each treatment were planted to wheat and two were left fallow. The fallow soils were sampled at intervals for determinations of available phosphorus, whereas the soils planted to wheat were sampled at the beginning of the experiment and after the wheat was harvested. Ammonium sulfate and potassium chloride were each applied at the rate of 200 pounds per acre to all soils. Superphosphate was applied at the rate of 300 pounds per acre and the other fertilizers[3] on a phosphorus equivalent basis. The treatments made and the results obtained on fallow soils are shown in Table 1.

The fertilizers were thoroughly mixed with the soil and placed in the pots. The moisture content of the soils was kept at about 50% of the saturation capacity of the soils during the experiment. The soils were potted March 20 and 21 and kernels of spring wheat were planted March 26. Four grams of sodium nitrate in 100 cc of water were applied to each pot on April 12. When the plants were about 6 inches high they were thinned to 14 plants per pot. The wheat was harvested May 26 at which time it was in full bloom. The plants were dried about 5 days at 60° to 70°C and weighed.

After the crop was harvested the soils were sampled and tested by

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[3] The fertilizers used in this experiment were furnished by Dr. W. H. Ross, Fertilizer and Fixed Nitrogen Investigations, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture.

TABLE 1.—*The availability of phosphate fertilizers by different methods.*

Sample No.	Fertilizer treatment	Mgm mycelial growth *A. niger*		Mgm P per 100 grams dry soil (Truog method)		
		June 22	July 20	June 22	July 20	Aug. 31
A-0	Check	307.8	407.6	0.45	1.96	0.90
A-4	Superphosphate high in Fe and Al*	328.5	417.3	0.46	1.61	0.86
A-10	Ammoniated superphosphate (2.48% ammonia)	376.6	439.8	Trace	1.73	0.74
A-12	Ammoniated superphosphate (6.83% ammonia)	311.6	488.0	Trace	1.11	0.87
A-13	Ammoniated superphosphate (8.66% ammonia)	351.1	507.8	Trace	1.69	0.83
B-4	Tricalcium phosphate (15.94% citrate-sol.)	235.7	390.7	Trace	1.86	0.65
B-5	Tricalcium phosphate (13.21% citrate-sol.)	285.7	400.7	Trace	1.49	0.84
B-6	4 parts tricalcium phosphate (21.24% citrate-sol.) and 1 part ammonium phosphate	317.1	391.1	Trace	1.51	1.32
B-13	Natural Fe and Al phosphate	340.5	420.8	0.93	1.77	1.02
B-14	Tennessee brown rock phosphate	370.5	441.9	0.49	1.84	1.00

*300 pounds per acre. Other phosphate fertilizers on phosphorus equivalent basis.

the growth of *Aspergillus niger*, by the Truog method, and by the Bray test. The results are presented in Table 2.

The data in Table 1 show that the available phosphorus content of all soils increased from the first to the second samplings and decreased from the second to the third sampling. There was apparently no relation between the amount of available phosphorus in the variously treated soils as measured by the two methods.

The data in Table 2 show that the soil treated with superphosphate (A-4) contained the most available phosphorus at planting time when measured by the growth of *A. niger* and the least amount by the Bray test. It was next to the highest by the Truog test. After the wheat was harvested, this soil still contained the highest available phosphorus content of any of the soils as measured by the growth of *A. niger*. The soil treated with ammoniated superphosphate (A-13) contained the most available phosphorus at planting time as measured by the Truog method and the rock phosphate treated soil contained the most after the crop was harvested. The yields of wheat were less on all treated soils than on the check soil.

EXPERIMENT II

In the second experiment three pots of soil of each treatment were planted to wheat and the fourth pot was left fallow. Ammonium sulfate was applied at the rate of 1,000 pounds per acre and potassium

TABLE 2.—*Availability of phosphate fertilizers by different methods.*

Sample No.	Fertilizer treatment	Soils sampled before planting crop			Yield of wheat in grams, dry weight	Soils sampled after crop was harvested		
		Mgm *A. niger*	Mgm P per 100 grams dry soil (Truog)	Bray test		Mgm *A. niger*	Mgm P per 100 grams dry soil (Truog)	Bray test
A-0	Check	323.2	0.65	1*	22.0	340.0	0.65	1
A-4	Superphosphate high in Fe and Al†	379.2	1.11	3	16.3	368.5	0.65	1
A-10	Ammoniated superphosphate (2.48% ammonia)	373.6	0.97	2	21.8	352.3	0.65	2
A-12	Ammoniated superphosphate (6.83% ammonia)	295.6	1.04	2	18.0	343.3	0.74	1
A-13	Ammoniated superphosphate (8.66% ammonia)	290.6	1.26	1	20.0	344.0	0.80	2
B-4	Tricalcium phosphate (15.94% citrate-sol.)	304.0	0.83	2	17.6	349.4	0.65	1
B-5	Tricalcium phosphate (13.21% citrate-sol.)	306.3	0.80	2	14.5	362.4	0.65	1
B-6	4 parts tricalcium phosphate (21.24% citrate-sol.) +1 part monoammonium phosphate	289.5	0.79	1	17.5	353.4	0.76	1
B-13	Natural Fe and Al phosphate	289.5	0.77	2	12.4	314.8	0.79	1
B-14	Tennessee brown rock phosphate	278.1	0.74	2	10.9	362.8	0.87	1

*1 = High; 2 = Medium; and 3 = Doubtful.

†300 pounds per acre; other phosphate fertilizers on a phosphorus equivalent basis.

chloride at the rate of 800 pounds per acre as a basic treatment on all soils. Superphosphate (A-1) was applied at the rate of 300 pounds per acre and the other fertilizers on a phosphorus equivalent basis. An outline of the treatments made is shown in Table 3. The fertilizers were thoroughly mixed with the soil and the soil placed in the pots. The moisture content of the soils was adjusted to approximately 50% of the saturation capacity and kept at this amount throughout the experiment. An interval of 3 weeks was allowed after the soil was treated before the wheat was planted. Twenty-one kernels of wheat were planted in each pot November 7 at a depth of 1 inch. When the plants were about 6 inches high they were thinned to 14 plants per pot. The wheat was harvested after a growing period of 5 months, dried, threshed, and weighed.

Three different samplings were made from the fallow soils in this experiment and the available phosphorus determined by the Bray field test, the growth of *A. niger*, the neutral ammonium citrate method, and the Truog method.

The relative amounts of available phosphorus in the fallow soils at the three samplings as shown by the Bray test are given in Table 3. The data in the table show a medium phosphorus content of all soils except the check, which was low at all samplings, and the soil treated with colloidal phosphate which was doubtful at the first sampling.

TABLE 3.—*Available phosphorus by the Bray test.**

Sample No.	Fertilizer treatment	Date sampled		
		Oct. 27	Jan. 12	Apr. 5
A-0	Check	0	0	0
A-4	Superphosphate high in Fe and Al†	xx	xx	xx
A-10	Ammoniated superphosphate (2.48% ammonia)	xx	xx	xx
A-12	Ammoniated superphosphate (6.83% ammonia)	xx	xx	xx
A-13	Ammoniated superphosphate (8.66% ammonia)	xx	xx	xx
B-4	Tricalcium phosphate (15.94% citrate-sol.)	xx	xx	xx
B-5	Tricalcium phosphate (13.21% citrate-sol.)	xx	xx	xx
B-6	4 parts tricalcium phosphate (B4) + 1 part monoammonium phosphate	xx	xx	xx
B-13	Natural Fe and Al phosphates	xx	xx	xx
B-14	Tennessee brown rock phosphate	xx	xx	xx
B-16	Colloidal phosphate	x	xx	xx

*O = Low; x = Doubtful; xx = Medium; and xxx = High.

†300 pounds per acre; other fertilizers on a phosphorus equivalent basis.

The relative amounts of available phosphorus in the fallow soils at the three samplings as shown by the growth of *A. niger* are given in Table 4. At the first sampling the best growth of *A. niger* was made on the soil treated with superphosphate (A-4) and the poorest growth on the soil treated with tricalcium phosphate (B-4). At the second and third samplings, however, the best growth of the mold was secured from the soil treated with the tricalcium phosphate (B-4).

TABLE 4.—*Available phosphorus by the growth of aspergillus niger.*

Sample No.	Fertilizer treatment	Mgm mycelial growth		
		Oct. 27	Jan. 12	Apr. 5
A-0......	Check	820.4	632.0	415.0
A-4......	Superphosphate high in Fe and Al*	945.1	685.0	465.0
A-10.....	Ammoniated superphosphate (2.48% ammonia)	845.1	685.0	437.0
A-12.....	Ammoniated superphosphate (6.83% ammonia)	802.3	645.0	459.0
A-13.....	Ammoniated superphosphate (8.66% ammonia)	940.0	675.0	465.0
B-4......	Tricalcium phosphate (15.94% citrate-sol.)	706.8	720.0	485.0
B-5......	Tricalcium phosphate (13.21% citrate-sol.)	737.8	645.0	426.0
B-6......	4 parts tricalcium phosphate (B4) + 1 part monoammonium phosphate	859.0	660.0	442.0
B-13.....	Natural Fe and Al phosphate	761.2	625.0	406.0
B-14.....	Tennessee brown rock phosphate	834.7	670.0	421.0
B-16.....	Colloidal phosphate	737.3	645.0	392.0

*300 pounds per acre; other fertilizers on a phosphorus equivalent basis.

The citrate-soluble phosphorus content of the fallow soils at the three samplings is shown in Table 5. At all three samplings, one of the tricalcium phosphate treated soils (B4, B5, or B6) contained the most citrate-soluble phosphorus. The soil treated with colloidal phosphate was lowest in citrate-soluble phosphorus at the first two samplings. The soils treated with the rock phosphate were low in citrate-soluble phosphorus at the first samplings, but the amount increased from the first to the third samplings. The ammoniated

TABLE 5.—*Available phosphorus by the neutral ammonium citrate method.*

Sample No.	Fertilizer treatment	Mgm P per 100 grams dry soil		
		Oct. 27	Jan. 12	Apr. 5
A-0......	Check	1.30	1.26	1.09
A-4......	Superphosphate high in Fe and Al*	1.60	1.58	1.39
A-10.....	Ammoniated superphosphate (2.48% ammonia)	1.68	1.75	1.43
A-12.....	Ammoniated superphosphate (6.83% ammonia)	1.65	1.86	1.58
A-13.....	Ammoniated superphosphate (8.66% ammonia)	1.55	1.62	1.51
B-4......	Tricalcium phosphate (15.94% citrate-sol.)	1.83	1.83	1.57
B-5......	Tricalcium phosphate (13.21% citrate-sol.)	1.70	1.67	1.78
B-6......	4 parts tricalcium phosphate (B4) + 1 part monoammonium phosphate	1.80	1.85	1.55
B-13.....	Natural Fe and Al phosphate	1.42	1.35	1.32
B-14.....	Tennessee brown rock phosphate	1.39	1.47	1.70
B-16.....	Colloidal phosphate	1.37	1.33	1.61

*300 pounds per acre; other fertilizers on a phosphorus equivalent basis.

superphosphate increased in neutral ammonium citrate-soluble phosphorus from the first to the second sampling but decreased again at the third date.

The available phosphorus in the fallow soils as measured by the Truog method is given in Table 6. The data in the table show that the soils treated with the colloidal phosphate was highest in available phosphorus at the first sampling, but that the rock phosphate (B-14) was the highest at the second and third dates. The ammoniated superphosphates showed large amounts of available phosphorus at all samplings. Superphosphate and the natural iron and aluminum phosphate were low in available phosphorus by this method at all samplings.

TABLE 6.—*Available phosphorus by the Truog method.*

Sample No.	Fertilizer treatment	Mgm P per 100 grams dry soil		
		Oct. 27	Jan. 12	Apr. 5
A-0	Check	1.13	1.07	1.05
A-4	Superphosphate high in Fe and Al*	1.39	1.22	1.33
A-10	Ammoniated superphosphate (2.48% ammonia)	1.35	1.43	1.43
A-12	Ammoniated superphosphate (6.83% ammonia)	1.86	1.90	1.70
A-13	Ammoniated superphosphate (8.66% ammonia)	1.86	1.78	1.67
B-4	Tricalcium phosphate (15.94% citrate-sol.)	1.86	1.78	1.60
B-5	Tricalcium phosphate (13.21% citrate-sol.)	1.82	1.78	1.65
B-6	4 parts tricalcium phosphate (B4) + 1 part monoammonium phosphate	1.97	1.96	1.78
B-13	Natural Fe and Al phosphates	1.40	1.00	1.29
B-14	Tennessee brown rock phosphate	1.90	2.22	1.97
B-16	Colloidal phosphate	2.05	1.78	1.27

*300 pounds per acre; other fertilizers on a phosphorus equivalent basis.

The data in Table 7 show that all the fertilizers increased the yield of wheat on Carrington loam and that the highest yields were secured by treatment with di- and tricalcium phosphates (B-2 and B-5). The colloidal phosphate was least effective of all the fertilizers tested in increasing wheat yield. The ammoniated superphosphate (A-10), superphosphate (A-1), bone ash, and rock phosphate high in iron and aluminum brought about relatively small increases in yield.

DISCUSSION

In the first experiment there seemed to be no correlation between the amount of available phosphorus in the soil as measured by the growth of *A. niger*, the Truog method, the Bray test, and the yield of spring wheat.

In the second experiment the Bray test indicated no difference in amount of available phosphorus in the soils treated with the various fertilizers and gave no indication, therefore, of the relative efficiency of the different fertilizers.

TABLE 7.—*Effect of phosphate fertilizers on yield of wheat in 4-gallon pots.*

Sample No.	Fertilizer treatment	Total dry weight in grams		
		Grain	Straw	Total
A-0......	Check	7.05	18.60	25.65
A-1......	Superphosphate (16.64% water-sol.)*	9.25	19.80	29.05
A-2......	Superphosphate (15.08% water-sol.)	8.66	23.10	31.76
A-4......	Superphosphate high in Fe and Al	8.49	25.31	34.30
A-10.....	Ammoniated superphosphate (2.48% ammonia)	8.13	20.64	28.77
A-11.....	Ammoniated superphosphate (5.36% ammonia)	10.14	24.84	34.98
A-12.....	Ammoniated superphosphate (6.83% ammonia)	9.01	24.02	33.03
A-13.....	Ammoniated superphosphate (8.66% ammonia)	8.63	23.04	31.67
A-14.....	Ammoniated superphosphate (4.71% ammonia)	10.41	24.35	34.76
A-15.....	Ammoniated superphosphate (4.36% ammonia)	9.05	25.18	34.23
B-1......	Monocalcium phosphate	10.23	24.89	35.12
B-2......	Dicalcium phosphate	11.79	25.18	36.97
B-4......	Tricalcium phosphate (15.94% citrate-sol.)	9.99	24.40	34.39
B-5......	Tricalcium phosphate (13.21% citrate-sol.)	10.33	28.31	38.64
B-6......	4 parts tricalcium phosphate (B4) + 1 part monoammonium phosphate	10.65	23.52	34.17
B-8......	Imported basic slag	10.54	21.13	31.67
B-9......	Steamed bone meal	10.62	23.39	34.01
B-10.....	Calcined phosphate	9.10	22.09	31.19
B-11.....	Fluorspar basic slag	9.40	24.53	33.93
B-12.....	Bone ash	8.43	20.18	28.61
B-13.....	Natural Fe and Al phosphate	8.14	21.07	29.21
B-14.....	Tennessee brown rock phosphate	10.07	21.71	31.78
B-15.....	Fluorapatite	9.51	20.48	29.99
B-16.....	Colloidal phosphate	7.30	19.10	26.40

*300 pounds per acre; other fertilizers on a phosphorus equivalent basis.

The growth of *A. niger* seemed to indicate some difference in the relative efficiency of the different phosphate fertilizers. In general, the soils treated with the commercial phosphate fertilizers contained a larger amount of available phosphorus than did those treated with the natural phosphates. A fairly close correlation existed between the amount of available phosphorus in the soils treated with the different phosphate fertilizers as measured by the growth of *A. niger* and the crop yields secured on these soils in this experiment.

The amount of citrate-soluble phosphorus was slightly higher in the soils treated with the commercial phosphate fertilizers than in the soils treated with the natural phosphate fertilizers. It was observed that the soil treated with the ammoniated superphosphate containing the highest percentage of ammonia showed the lowest content of available phosphorus. With the other two ammoniated superphosphates, the correlation between high ammonia content and low available phosphorus content existed only at the first sampling. The low availability of phosphorus in highly ammoniated superphosphates was probably due to the formation by the ammonia of phosphates less soluble in neutral ammonium citrate. A relatively low yield of wheat was obtained on the soil treated with the highly ammoniated superphosphate which was shown to be low in available phosphorus by the neutral ammonium citrate method. The relative efficiency of the different phosphate fertilizers as shown by the neutral ammonium citrate method correlated closely with crop response in the case of 5 of the 10 phosphate fertilizers used in this experiment.

The largest amount of available phosphorus, as measured by the Truog method, was found in the soils treated with rock phosphate and colloidal phosphate. The two soils treated with the ammoniated superphosphates high in ammonia contained relatively large amounts of available phosphorus, but the yields of wheat were low. However, a close correlation existed between the relative efficiency of the superphosphate, tricalcium phosphate (B-6), the natural iron and aluminum phosphate, and the rock phosphate, as measured by the Truog method and crop yields.

The commercial phosphate fertilizers were more effective than the natural phosphate fertilizers in stimulating grain yields of wheat, except in the case of rock phosphate which stimulated crop growth almost equally as well as the most efficient commercial fertilizer. The dicalcium phosphate and one tricalcium phosphate were the most efficient while the colloidal phosphate was the least efficient in stimulating wheat yields. The crop yield from each of the phosphate treated soils correlated closely with the content of available phosphorus as measured by the growth of *A. niger* and by the neutral ammonium citrate and the Truog methods in the second experiment.

SUMMARY AND CONCLUSIONS

Two experiments were carried out for the purpose of determining the relative efficiency of certain ammoniated superphosphates and other phosphate fertilizers by the use of various methods.

These experiments consisted in the growing of wheat on Carrington loam in 4-gallon pots in the greenhouse and the sampling of fallow Carrington loam in similar pots, both cropped and fallow soils being treated with the various phosphate fertilizers. Data were obtained on the crop response to the different fertilizers and the available phosphorus content of the differently treated soils as measured by the Bray test, the neutral ammonium citrate method, the Truog method, and the growth of *A. niger*.

In general, a close correlation was found between the crop response to these fertilizers and the amount of available phosphorus in the variously treated soils as determined by all the laboratory methods except the Bray test. It was also noted that the superphosphates were more efficient than the natural rock phosphates in increasing the crop and the soils treated with superphosphate were higher in content of available phosphorus than the soils treated with rock phosphate by all methods except by the Truog test. However, no one test showed the efficiency of all fertilizers accurately under all conditions.

THE EFFECT OF DIFFERENT METHODS OF STORING CHICKEN MANURE ON THE VIABILITY OF CERTAIN WEED SEEDS[1]

G. L. STOKER, D. C. TINGEY, and R. J. EVANS[2]

Many weeds seeds are carried in hay, straw, and feeds which eventually find their way into manure and are later hauled to the land. This is especially true in the case of poultry manure where grain containing weed seeds is fed in the litter as scratch feed. The rapid increase in poultry raising in Utah has resulted in large quantities of this manure, with its accompanying benefits and hazards. Farmers would not hesitate to use the manure if the weed dangers could be eliminated, but many refuse to use it under present conditions. Morning glory seeds (*C. arvensis* L.) have been known to remain in the soil for 40 years (7)[3] and still retain their viability. Once the soil is infested, the dangers may remain for long periods of time.

REVIEW OF LITERATURE

Experiments have been conducted to determine the viability of seeds under various conditions and for various periods of time. Only those pertaining directly to the study reported are reviewed.

Substances such as alfalfa, casein, peptone, and sugar were added to a silt loam soil in which seeds of alfalfa, buckwheat, castor bean, red clover, corn, cotton, flax, hemp, white lupine, mustard, oats, serradella, soybean, sunflower, sweet pea, and wheat were planted (8). It was found that the nitrogenous substances did not seriously injure germination unless used in excessive amounts. Sugar increased bacterial growth and retarded the rate of germination; and when used in large amounts, the percentage of germination was decreased.

✓ The viability of many seeds was destroyed after being buried in silage (3, 12). However, morning glory and velvet leaf gave a higher germination than seed which had not been placed in the silo.

As early as 1879, Beal (1) at East Lansing, Michigan, buried 23 species of seeds in sand at a depth of approximately 20 inches. At the end of a 40-year period, 10 of the 23 species produced sprouts (5). ✓ In 1902, Duvel (6) set up an experiment using Beal's general plan. He used 109 species, representing 84 genera and 34 families. These seeds were buried in well-baked earthen pots at three different depths. It was concluded that seeds of most weeds when plowed under, during the period of normal crop rotation, do not perish and that weed seeds survive better than crop seeds (9). In experiments at Rothamsted (2), it was found that while certain seeds appear to lie dormant in the soil for long periods, they may germinate under favorable conditions. Similar results were obtained in Iowa (4). Green manure may also injure the germination of certain seeds (7).

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[2] Graduate Student, Assistant Agronomist, and Agronomist, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 609.

The effect of fermenting manure on the germination of weed seeds has been studied in Iowa (11) and in Maryland (10). At both places horse and cow manures used separately and the two mixed in equal parts were used. At Maryland 52 varieties of seeds were placed in the manure for from 1 to 6 months. All seeds failed to germinate after the 1-month period. At Iowa similar results were obtained in 1907 for the 60-day to the 6-month periods. For the 1-month period six species germinated. In 1908, 31 different weed seeds as well as seeds of a few cultivated plants were left in horse manure for 5 weeks, the highest percentage germination of any weed seed being 1%. Most of them failed to germinate.

METHODS AND MATERIAL

MANURE

The material for this experiment consisted of chicken manure obtained from the Experiment Station poultry houses. The dry autumn (1932) kept the manure practically air-dry. The manure was gathered and placed in both large and small piles. The large piles contained approximately 2⅔ cubic yards of dry manure, while the small piles contained approximately 1⅓ cubic yards. Seeds were placed in the experimental piles as built. The approximate sizes of these piles were as follows: Large piles, 82 inches in diameter at the base and 40 inches in height; small piles, 60 inches in diameter and 25 inches in height. Exceptions to this were those piles which were compacted, these being somewhat less in height and flattened on top.

Twelve piles (six large and six small) were used and continued over a period of 4 months, four small piles being used for a period of 50 days.

SEEDS

The weed seeds used included wild morning glory (*Convolvulus arvensis* L.), whitetop (*Lepidium draba* L.), and Russian knapweed (*Centaurea picris* Poll). The seeds were collected in the fall of 1932.

Seeds of all three species were germinated before being placed in the manure. Some difficulty was encountered in getting the seeds of whitetop and morning glory to germinate. The seeds were treated in various ways, but none of the methods increased the germination of whitetop. However, germination did increase with the age of the seed, so that after 2 months a reasonably high germination was obtained on non-injured seed. The studies showed that a high percentage germination of morning glory could be obtained by treating with 33 normal sulfuric acid for 15 minutes. This treatment for morning glory seed was necessary throughout the experiment, even after the seed had remained in the center of a pile of manure which had been wet and packed for a period of 4 months. The seed coats of many of the seeds of morning glory were impermeable, thus preventing the absorption of water.

CONTAINERS

In order to recover the seeds and at the same time bring them into direct contact with the manure, wire-mesh containers were used.

These containers were made of galvanized wire (Fig. 1). Approximately 600 seeds of each species were placed in separate containers. Sixteen containers of each of the three species were placed in each pile, making a total of 768 in all, with approximately 600 seeds in each container. This made about 153,600 seeds of each species, or a total of 460,800 seeds.

A piece of light baling wire was fastened to the container so that it could be pulled out of the pile with little or no disturbance to the manure.

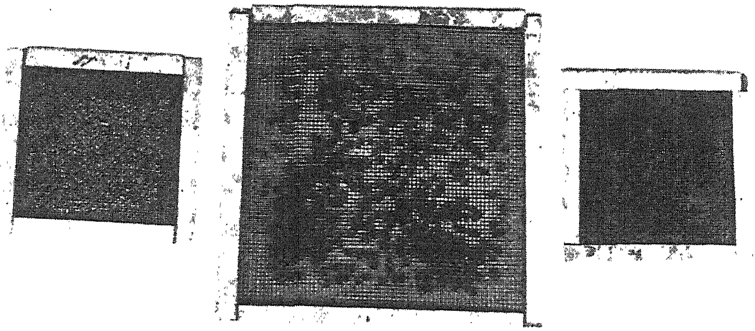

FIG. 1.—Showing wire-mesh containers with seeds. *Left*, whitetop (*Lepidium draba* L.); *Center*, Morning glory (*Convolvulus arvensis* L.); *Right*, Russian knapweed (*Centaurea picris* Poll).

The containers were placed at two different layers in the piles, as shown in Fig. 2. The height of the pile was divided as nearly as possible into thirds, the top and bottom layers being at one-third and two-thirds the distance, respectively. The two layers were similar. Arrangements were made to take out baskets from the top layer on the opposite side to those taken from the bottom layer.

The center containers of the bottom layer averaged about 20 inches from the edge, while those of the top layer averaged about 17 inches. The outer containers were about 9 inches from the edge of the bottom layer and about 8 inches from the edge of the top layer. Twelve containers were taken from each pile at four different periods, namely, three from the bottom center, three from the bottom edge, three from the top center, and three from the top edge of the pile.

GERMINATION OF SEED IN LABORATORY

Upon removal from the manure piles, a sample of 100 seeds taken from each container was germinated on the surface of blotter paper for a period of 30 days. A similar sample was germinated in the soil for a period of 2 months. Where the germination test showed that the viability of the seeds was destroyed, the remaining seeds from those particular lots which were not used in this first test were placed in the soil to determine their viability further. Similar seeds kept under reasonably good storage conditions were used as checks.

TREATMENT AND RESULTS

Six treatments were continued over a period of 4 months and two over a period of 50 days. The six treatments were made on both large and small piles. The first treatment consisted of litter and droppings[4] mixed in the same proportion as was obtained on cleaning the poultry house. The second was litter[5] alone. The third was litter alone with water added and the pile compacted. One hundred gallons of water were used in the large piles and 70 gallons in the small piles.

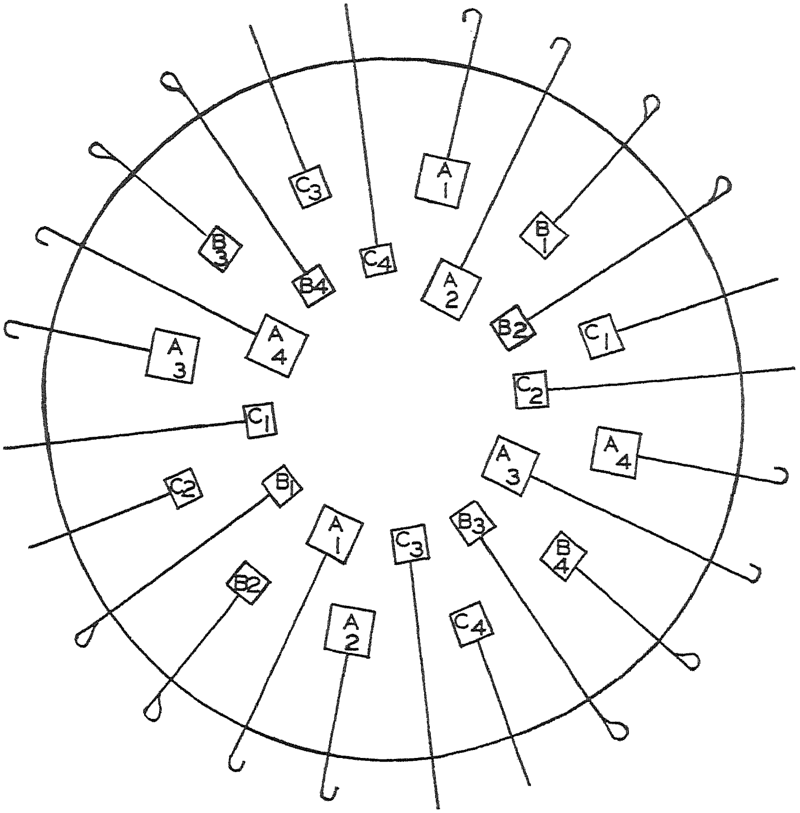

FIG. 2—Showing arrangement of wire containers for one layer in the pile. Nos. 1, 2, 3, and 4 represent containers removed at different intervals. *A* = Morning glory; *B* = Whitetop; and *C* = Russian knapweed.

The two treatments, which continued for a period of 50 days, consisted of duplicate small piles (387 pounds) composed of litter. Two piles were nearly saturated (2) by adding 100 gallons of water to each, while to each of the other two piles 50 gallons were added. It was left loose to make conditions favorable for rapid heating.

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[4] Manure taken from the dropping boards.
[5] Litter consisted of grain straw and floor droppings.

The seeds were taken from these four piles at intervals, as shown in Tables 1 and 2. At the end of the first 10-day period the percentage germination of whitetop and Russian knapweed seeds was extremely low (Table 1). At the end of the 20-day period and thereafter, whitetop and Russian knapweed seeds failed to germinate.

Morning glory seed showed as high a percentage germination after being in manure 50 days as it did at the beginning of the experiment.

To obtain a completely accurate record of the temperatures of the various piles and in different locations would have required a rather large number of thermographs which were not available, consequently, only rough determinations were made.

The experiment began December 10 and on December 15 three of the four piles in the short series had a temperature of between 65° and 70° C at the top center of the pile. The other pile had started to heat a little on the south side. The following day it was heating to a temperature of between 65° and 70° C. The temperature at the sides of the pile, 9 inches from the edge, was approximately 50° C. These temperatures were taken during sub-zero weather. When the seeds were taken out for the first time (December 20), all piles showed temperatures of 65° to 70° C. On December 30 (at the end of 20 days) one pile of each treatment had about the same temperature as did the surrounding atmosphere. The other two were about 15° and 25° above atmospheric temperature, that which was slow in starting to heat having the higher temperature. The maximum temperature of the piles which were moistened and compacted was about 45° C. This was lower than the maximum temperature of the four piles which were moistened and left loose to heat and which had been run for a period of only 50 days.

Seeds were taken from the other 12 piles at monthly intervals and the results checked with those obtained on the four piles which had been run for a shorter period of time.

MORNING GLORY

As shown in Table 2, the viability of morning glory seed was neither destroyed nor reduced after having been in the manure for a period of 4 months, even though the manure had been moistened and compacted. The check at the end of the experiment gave a lower germination than any of the treatments. There seems to be no appreciable difference between percentage germination in soil and on blotter paper. Likewise, there seems to be no appreciable difference between the large and small piles, except where moisture was added and even here the difference is slight. For a period of 4 months, viability is not markedly affected by any of the treatments. The only observable difference was that those seeds which had been in moistened manure germinated a little sooner and more uniformly than did those which had been in dry manure.

WHITETOP

Percentage germination of whitetop seed was lower and more variable than percentage observed for morning glory seed (Table 2). A greater variation would be expected because the viability of white-

TABLE 1.—*Effects of different treatments of chicken manure in small piles and duration of time on viability of morning glory* (*C. arvensis*), *whitetop* (*L. draba*), *and Russian knapweed* (*C. picris*).

Treatment	Percentage germination											
	Check before treatment*		Period of time seeds remained in manure								Check, Apr. 3†	
			Dec. 3–Dec. 20		Dec. 3–Dec. 30		Dec. 3–Jan. 9		Dec. 3–Jan. 29			
	Soil	B.P.‡	Soil	B.P.	Soil	B.P.	Soil	B.P.	Soil	B.P.	Soil	B.P.
Morning Glory												
Litter (loose), with 100 gallons water added	84.0	86.0	39.0	46.6	82.8	87.0	86.8	87.6	85.9	85.1	61.0	72.0
Litter (loose) with 50 gallons water added	84.0	86.0	30.8	39.0	73.6	78.6	73.6	82.6	77.6	80.1	61.0	72.0
Whitetop												
Litter (loose) with 100 gallons water added	30.0	85.0	0	0	0	0	0	0	0	0	57.0	82.0
Litter (loose) with 50 gallons water added	30.0	85.0	0.3	0	0	0	0	0	0	0	57.0	82.0
Russian Knapweed												
Litter (loose) with 100 gallons water added	38.5	86.0	0.3	0.1	0	0	0	0	0	0	66.0	64.0
Litter (loose) with 50 gallons water added	38.5	86.0	0	0	0	0	0	0	0	0	66.0	64.0

*Germination of seed before placing in manure.

†Similar seed kept under reasonably good storage conditions.

‡Blotter paper.

TABLE 2.—*Effects of different treatments of chicken manure and duration of time on viability of morning glory (C. arevensis), whitetop (L. draba), and Russian knapweed (C. picris) seeds, average of four lots of seed in each pile and duplicate piles for each treatment.*

Treatment	Size of pile	Percentage germination											
		Check before treatment*		Period of time seeds remained in manure								Check, Apr. 3†	
				Dec. 3–Jan. 3		Dec. 3–Feb. 3		Dec. 3–Mar. 3		Dec. 3–Apr. 3			
		Soil	B.P.‡	Soil	B.P.	Soil	B.P.	Soil	B.P.	Soil	B.P.	Soil	B.P.
						Morning Glory							
Litter and droppings mixed	Large	84.0	86.0	86.4	94.0	88.4	86.5	88.0	92.0	84.9	88.0	67.0	59.0
	Small	84.0	86.0	78.9	92.8	88.8	88.0	86.5	90.1	87.4	88.9	67.0	59.0
Litter alone	Large	84.0	86.0	89.8	90.4	89.6	92.3	86.5	90.6	88.6	91.1	67.0	59.0
	Small	84.0	86.0	88.9	90.5	89.3	87.6	89.3	88.6	89.6	91.0	67.0	59.0
Litter alone, moistened, and compacted	Large	84.0	86.0	84.4	83.9	85.1	84.8	84.5	86.5	83.3	87.0	67.0	59.0
	Small	84.0	86.0	86.5	85.3	88.9	89.0	88.3	88.8	87.9	88.9	67.0	59.0
						Whitetop							
Litter and droppings mixed	Large	30.0	85.0	0.4	5.6	0.3	3.0	0.8	1.3	7.1	4.4	16.0	10.0
	Small	30.0	85.0	5.4	73.3	10.0	53.1	17.4	46.1	17.5	10.1	16.0	10.0
Litter alone	Large	30.0	85.0	4.4	75.0	13.4	75.0	3.4	56.6	43.4	15.6	16.0	10.0
	Small	30.0	85.0	6.3	60.0	6.1	35.9	6.3	27.1	22.9	9.0	16.0	10.0
Litter alone, moistened, and compacted	Large	30.0	85.0	0	0	0	0	0	0	0§	—	16.0	10.0
	Small	30.0	85.0	0	0	0	0	0	0	0	—	16.0	10.0

						Russian Knapweed							
Litter and droppings mixed.............	Large	38.5	86.0	3.3	10.9	3.4	7.6	3.4	7.0	0.4	1.5	46.0	62.0
	Small	38.5	86.0	20.1	83.0	38.4	74.3	23.8	45.6	5.9	8.8	46.0	62.0
Litter alone............	Large	38.5	86.0	19.9	84.1	25.4	59.9	24.8	65.1	28.8	52.1	46.0	62.0
	Small	38.5	86.0	20.4	82.3	27.8	52.0	24.8	41.9	4.8	8.4	46.0	62.0
Litter alone, moistened, and compacted.......	Large	38.5	86.0	0	0	0.05‖	0.3‖	0	0	0**	----	46.0	62.0
	Small	38.5	86.0	0	0	0	0	0	0	0	----	46.0	62.0

*Germination of seed before placing in manure.

†Similar seed kept under reasonably good storage conditions.

‡Blotter paper.

§All seed was germinated in the soil.

‖This lot of seed was taken from the outer edge of one of the piles where it could have been slightly drier and better aerated, and it is highly possible that this accounts for the remaining viability of these few seeds.

**All seed was germinated in the soil.

top seed is markedly affected when the manure is moistened. Those piles consisting of litter and droppings mixed and of litter alone were dry at the beginning, but as the snow melted in the spring they became moistened and started to heat. In some cases only parts of the top of the pile heated, while in others the entire upper part of the pile heated which would affect the seeds according to their location in the pile.

The viability of seeds in manure consisting of litter and droppings mixed and of litter alone was not destroyed in the 4 months, whereas in the litter alone, moistened and compacted, it was destroyed at the end of 1 month. The large pile of litter and droppings mixed reduced somewhat the percentage germination of the seeds. Viability of seeds located at the bottom center and top edge of the pile was destroyed within a month and that of seed at the top center at the end of 1 month. The large pile of litter and droppings mixed reduced somewhat the percentage germination of the seeds. Viability of seeds located at the bottom center and top edge of the pile was destroyed within a month and that of seed at the top center by the end of 2 months. The small piles of litter and droppings mixed gave results similar to those obtained with litter alone.

RUSSIAN KNAPWEED

The effect of manure on viability of Russian knapweed seed was similar to that on whitetop (Table 2). The mixture of litter and droppings and the litter alone did not destroy the viability during the 4-month period, although the large pile of litter and droppings mixed reduced the percentage germination and destroyed the viability of seeds located in certain sections of the pile. The viability of seeds in the litter alone, moistened and compacted, was destroyed after 1 month with the exception of a few seeds taken out on February 3 from the bottom edge of one pile. This is possibly due to the fact that the container was near enough to the edge of the pile that a few seeds were allowed to escape the effects of the moistened manure. Out of approximately 4,800 seeds, only 4 germinated.

SUMMARY

Seeds of morning glory (*Convolvulus arvensis* L.), whitetop (*Lepidium draba* L.) and Russian knapweed (*Centaurea picris* Poll) were put in wire containers and placed in chicken manure, stored in different ways for various periods of time, and then germinated in soil and on blotter paper.

Seeds were removed from the various piles and germinated at different intervals, the shortest being 10 days and the longest 4 months.

In no case was the viability of morning glory seed destroyed.

The viability of whitetop and Russian knapweed seeds was destroyed after being in the moist, loose manure for 20 days or after being in the moist compacted manure for 1 month.

In the unmoistened piles the viability of whitetop and Russian knapweed seeds was not completely destroyed at the end of 4 months.

LITERATURE CITED

1. BEAL, W. J. The vitality of seeds buried in the soil. Mich. Agr. Exp. Sta. Bul. 5. 1885.
2. BRENCHLEY, WINIFRED E. Buried weed seeds. Jour. Bd. Agr. (London), 24 : 299–306. 1917. Abs. in Country Life, 43 : 335–336. 1917.
3. CALL, L. E. The effects of the ensiling process and of freezing upon the germination of weed seed. Kan. Agr. Exp. Sta. Biennial Rpt., 1926–28 : 47. 1928.
4. CURTISS, C. F. Seed investigations. Iowa Agr. Exp. Sta. Ann. Rpt., 1917–18 : 24. 1918.
5. DARLINGTON, H. T. Dr. W. J. Beal's seed-viability experiment. Amer. Jour. Bot., 9 : 266–269. 1922.
6. DUVEL, J. W. T. Vitality of buried seeds. U. S. D. A. Bur. Plant Ind. Bul. 83 : 22. 1905.
7. FRED, E. B. Relation of green manures to the failure of certain seedlings. Jour. Agr. Res., 5 : 1161–1176. 1916.
8. ————. The effect of certain organic substances on seed germination. Soil Science, 6 : 333–349. 1918.
9. GOSS, W. L. The vitality of buried seeds. Jour. Agr. Res., 29 : 349–362. 1924.
10. OSWALD, E. I. The effect of animal digestion and fermentation of manures on the vitality of seeds. Md. Agr. Exp. Sta. Bul. 128 : 265–291. 1908.
11. PAMMEL, L. H., and KING, C. M. Notes on eradication of weeds, with experiments made in 1907 and 1908. Iowa Agr. Exp. Sta. Bul. 105 : 265–300. 1909.
12. WASHBURN, R. M. The ensiling of weeds. Vt. Agr. Exp. Sta. Bul. 170 : 131–134. 1912.

A MAGNESIUM DEFICIENCY INDUCED BY PREVIOUS FERTILIZER TREATMENTS[1]

H. C. KNOBLAUCH and T. E. ODLAND[2]

The development of certain chlorotic conditions in the potatoes on the phosphate experiment of the Rhode Island Experiment Station plats gave rise to a hypothesis of a possible magnesium deficiency in the soil. The disorder was noted to be more severe with certain fertilizer treatments. The investigations reported in this paper cover a series of field and greenhouse experiments with potatoes to determine if a lack of magnesium in the soil was responsible for the observed disorder and whether any element in the previous fertilization facilitated the magnesium deficiency.

EXPERIMENTAL

The soil used in this experiment, Merrimac silt loam, occurs on low level terraces and is fairly uniform in texture and structure. The average depth to gravel is about 34 inches.

Investigations at the experimental plats were conducted on two adjoining plats of the phosphate experiment. This experiment was started in 1894 for testing the value of different carriers of phosphorus.

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[1] Contribution from the Department of Plant Industry, Rhode Island Agricultural Experiment Station, Kingston, R. I. Published by permission of the Director of Research as Contribution No. 453. Also presented at the annual meeting of the Society held in Chicago, Ill., Nov. 17, 1933. Received for publication January 4, 1934.

[2] Assistant Agronomist and Agronomist, respectively.

It has continued in this capacity to the present time. The plats are two-fifteenths acre in size. The rotation used consists of 2 years of truck crops followed by 2 years of grass. Plats used in this experiment are divided into north and south halves for special fertilizer treatments.

During the past 8 years the following fertilizing plan has been in effect for the cultivated crops: Plats 64 and 66, north halves, approximately 2,000 pounds of a 4–8–8; plat 64, south half, 2,000 pounds of a 4–8–12; and plat 66, south half, 2,000 pounds of a 6–8–8. When in grass the amount has been about half of this. Nitrate of soda and sulfate of ammonia were used to supply the nitrogen, each supplying one-half. The phosphoric acid was supplied as superphosphate and the potash as muriate of potash.

The plats have not been limed since 1919. The pH varies from 5.12 to 5.28. This variation is probably of no significance. The lime requirement is about 3,000 pounds of CaO per acre.

During the season of 1931 the potatoes growing on these plats were chlorotic and were making very poor growth. A small application of magnesium sulfate to some of the hills caused a very marked improvement.

No specific treatment was attempted in 1931 because of the late date at which the probable cause was isolated. The yields obtained from the two plats used in this experiment are presented in Table 1.

TABLE 1.—*Potato yields in bushels per acre on the experimental plats in 1931.*

Plat	Large	Small	Total
64N	274	4	278
64S	139	5	144
66N	305	4	309
66S	175	5	180

From these figures it may be seen that the extra potash application caused a decrease in yield of 134 bushels per acre. In other investigations with potatoes at this Station under less acid soil conditions, it has been found that a fertilizer relatively high in potash produces the largest yields. While the high nitrogen caused a depression of 129 bushels per acre, the situations are not entirely comparable. An unbalanced condition of any element in the soil perhaps leads to a less favorable assimilation of the others, but an excess of nitrogen has caused an unfavorable response with potatoes when the other elements were supplied in what was thought to be optimum amounts.

Early in the growing season of 1932 the same disorder was observed on these plats. Accordingly, two of the four rows of potatoes on each plat were treated with magnesium sulfate at the rate of 200 pounds per acre, which is the equivalent of 32.7 pounds of MgO. The response on the two plats used in this study is shown in Table 2.

From the average yield of the treated and untreated rows it will be seen that the magnesium sulfate application gave an increase of 107 bushels per acre. Of special significance is the fact that the high

TABLE 2.—*Potato yields in bushels per acre on the experimental plats with and without magnesium in 1932.*

Plat	With magnesium			Without magnesium		
	No. 1	No. 2	Total	No. 1	No. 2	Total
64N	229	44	273	109	55	164
64S	171	36	207	80	47	127
66N	236	32	268	114	45	159
66S	245	34	279	112	32	144
Average	220	36	256	104	45	149

potash plat yielded 37 bushels less per acre than the north half with the regular fertilizer. Also, it should be noted that applying magnesium to this plat increased the yield from 127 to 207 bushels per acre. With the application of magnesium the high potash plat yielded 66 bushels less than with the regular fertilizer. While the high nitrogen plat is somewhat depressed in yield on the untreated half, it will be noted that supplying magnesium brought both halves of this plat to about the same yield.

In 1933 the study was enlarged to include the entire plat instead of four rows as had formerly been the case. Under this arrangement the plats were divided into east and west halves for magnesium treatment. The magnesium sulfate was changed from 200 to 150 pounds per acre and applied in the rows with the fertilizer. The untreated halves did not develop as serious a condition as was noted the two previous years. The yields obtained on the treated and untreated halves are given in Table 3.

TABLE 3.—*Potato yields in bushels per acre on the experimental plats with and without magnesium in 1933.*

Plat	With magnesium			Without magnesium		
	No. 1	No. 2	Total	No. 1	No. 2	Total
64N	229	34	263	94	42	136
64S	239	23	262	131	30	161
66N	221	37	258	127	34	161
66S	254	21	275	141	15	156
Average	236	29	265	123	30	153

The beneficial result from magnesium is again very apparent, the actual increase in yield being 112 bushels per acre. The notable point is that the high potash plat out-yielded the regular fertilizer application. This is contrary to any previous results. During the growing season of 1933 the amount of rainfall was rather limited. The high potash half is on a somewhat lower and slightly heavier soil. It is possible that the greater amount of moisture accumulated and retained on this end of the plat accounts, in part, for the greater yield.

OUTLYING FIELD STUDIES

In addition to the experimental plat studies, tests were carried on in a potato field at Slocum, Rhode Island, where it was reported that the same physiological disorder was occurring. The soil at Slocum is very similar to that found on the experimental plats. The field has been planted to potatoes for a number of years with a heavy annual application of fertilizer. The pH was somewhat lower than that on the experimental plats, being 4.16. A ton per acre of a 4-8-8 fertilizer was applied uniformly to all plats. Magnesium was added to this in various amounts and in different forms, as shown in Table 4. Each treatment was applied in triplicate and the yields represent the average of three plats in each case. The results are presented in Table 4.

TABLE 4.—*Yield of potatoes with different treatments on the H. K. Champlin Farm, Slocum, Rhode Island, 1932.*

Magnesium supplement		MgO in lbs. per acre	Yield in bu. per acre		
Lbs. per acre	Material		No. 1	No. 2	Total
	None		292	22	314
100......	Magnesium sulfate	16.3	403	23	426
300......	Magnesium sulfate	49.1	399	17	416
300...... 500......	Magnesium sulfate Calcium limestone	52.8	418	19	437
150......	Magnesium hydrate	48.4	417	20	437
300......	Magnesium hydrate	96.7	420	20	440
500......	Magnesium hydrate	161.2	397	24	421
500......	Magnesium limestone	100.6	416	28	444
	None		344	21	365
1,000......	Magnesium limestone	201.3	394	25	419
500......	Calcium limestone	3.6	342	27	369
1,000......	Calcium limestone	7.3	318	27	345
	Sulfate of potash-magnesia	57.5	407	25	432
500......	Sulfate of potash-magnesia calcium limestone	61.1	438	20	458

A very significant response will be noted wherever magnesium was applied. The 100-pound application of magnesium sulfate gave an increase of 87 bushels per acre over the average of all checks. The 300-pound application was not superior to the 100-pound treatment. With an application of 300 pounds of magnesium sulfate and 500 pounds of calcium limestone there was an increase of 98 bushels over the check. A 150-pound application of magnesium hydrate was found to give as good results as were obtained with a 300- or 500-pound application. Applications of 500 or 1,000 pounds per acre of magnesium limestone produced yields comparable to those obtained with hydrated lime. About 10% of the tubers from the 1,000-pound treatment were affected with scab. Very little scab was noticeable on the tubers from the other treatments. When the potash and magnesium were supplied in sulfate of potash-magnesia, an increase of 93 bushels per acre over the checks was obtained.

GREENHOUSE STUDIES

Soil was taken from the high-potash plat (64S) for special greenhouse studies in 1933. The potatoes were grown in Wagner pots. The basal fertilizer was equivalent to 3,000 pounds of a 4-8-2, while the extra potash was equal to 3,000 pounds of a 4-8-10. The basal fertilizer used was abnormally low in potash because of the large supply already in the soil from the accumulative effect of past years. The supplement treatments and the weights of tubers harvested from each treatment are given in Table 5.

TABLE 5.—*Tuber weights in grams grown in the greenhouse with different fertilizer treatments, 1933.*

Supplement	Weights of tubers, grams
None	137.6
Magnesium sulfate	176.3
Magnesium sulfate + extra potash	174.5
Extra potash	106.1

From Table 5 it will be seen that the extra potash treatment resulted in the lowest yields and that the magnesium sulfate was very effective in overcoming the extra potash.

DISCUSSION

It is generally assumed that the degree of crop response to a certain element is a measure of the importance of that element. Accordingly, if an element which is thought to be deficient is supplied and if a significant response is obtained, one should have demonstrated the importance of the deficient element.

The reasons for the magnesium deficiency may be summed up with a consideration of three points, namely, a continuous loss by leaching, a loss from crop removal, and that the fertilizers applied have been relatively low in magnesium. The losses by crop removal are considered insufficient to bring about the present deficiency.

Losses resulting from normal leaching on an acid soil where little or no magnesium has been applied do not fully explain the reason for the magnesium deficiency on the high-potash plat. There is a continual change in the colloidal complex, both organic and inorganic, and consequently elements are always being freed for leaching or for plant use. This process is going on continuously regardless of the elements present. On the high potash soil it would seem that the displacement of the magnesium by the high potash application may have augmented the outgo of magnesium for the greater deficiency in this soil.

The main consideration is that there seems to be a continual displacement of the magnesium and calcium in the soil by the excess concentration of potassium on the high potash soil. The smaller response from the magnesium application on the high potash soil is undoubtedly a function of the cation concentration. Results obtained by Bartholomew and Jansen[3] indicate that there is an optimum concentration of potassium in the soil for the assimilation of carbohydrates by the plant and that concentrations above or below this will greatly reduce assimilation. It is also reasonable to believe that the plant would take in more potassium than was needed under concentrated soil conditions.

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[3] BARTHOLOMEW, R. P., and JANSEN, G. Rôle of potassium. Ark. Agr. Exp. Sta. Bul. 246 : 27–29. 1929.

In experiments by Hoagland and Davis,[4] it was concluded that the concentration of a certain ion may become so low that a plant is unable to absorb enough of it to complete its growth. In this experiment during the early growth of the potato the ionic concentration was probably sufficient for the needs of the plant, but with increases in the rate of growth and consequent reduction in the magnesium concentration the critical point was reached and symptoms of nutritional deficiencies developed. The ionic concentration of the soil solution and its relation to the ions absorbed by the plant must be considered in connection with the intake of magnesium under this situation. With barley in solution cultures, it was found by Hoagland[5] that a comparatively low concentration of sodium decreased the absorption of calcium, magnesium, and potassium. From this finding Hoagland reasons further that potassium can influence the absorption of calcium. The situations are not entirely comparable due to the dynamic properties of the soil solution, but it does seem logical to extend this reasoning a step further. If potassium will influence the absorption of calcium, it seems that one is justified in concluding that it may influence the absorption of magnesium.

SUMMARY

In recent years potatoes growing on certain plats of the Rhode Island Agricultural Experiment Station have been found to be chlorotic and to make very poor growth. This condition suggested a deficiency in some essential element. A small application of magnesium sulfate to some of the plants partially corrected the disorder. The investigations reported in this paper cover both field and greenhouse experiments designated to determine if a lack of magnesium in the soil was the chief cause of the disorder; and, if so, whether any element in the previous fertilization helped bring about the deficiency.

With a fertilizer high in potash and on an acid soil, the yield was much reduced from that obtained with the standard fertilization. When magnesium sulfate was applied to the high-potash soil in 1931 and 1932, a significant increase in yield was obtained. However, supplementing the normal fertilization with magnesium sulfate gave a much larger relative increase. In 1933, a significant response was also obtained from the magnesium sulfate, but the depression in yield observed the two previous years with the high-potash soil did not occur. When lime is used the best yields of potatoes are usually obtained on those plats with a relatively high potash fertilizer. In experiments where different magnesium sources were used all were found effective when supplying a minimum of 20 pounds of MgO per

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[4] HOAGLAND, D. R., and DAVIS, A. R. Suggestions concerning the absorption of ions by plants. New Phytol., 24 : 99–111. 1925.

[5] HOAGLAND, D. R. The absorption of ions by plants. Soil Science, 16 : 225–246. 1923.

acre. Larger quantities than this did not give further increases in yield.

The greenhouse tests with a high potash soil showed a significant response to magnesium sulfate. While supplying magnesium was beneficial it did not give as large an increase with the high-potash fertilizer as was obtained from the low-potash and magnesium treatment.

It was found that magnesium was the deficient element and that a high potash supply in the soil under acid conditions facilitates a magnesium deficiency. Probably, the cause of the magnesium deficiency is that the fertilizers applied have been relatively free from magnesium and that there has been a continual loss of this element by crop removal and leaching. Further, it is probable that the high concentration of potassium has largely displaced the available magnesium of the soil and that the excess concentration of potassium has interfered with magnesium absorption.

For control of the disorder, under our soil conditions, it is recommended that magnesium limestone supplying 25 to 35 pounds of MgO per acre be applied.

BORDER EFFECT IN SUGAR BEETS[1]

G. W. DEMING and H. E. BREWBAKER[2]

It is well known in ecology that because of the competition among plants for light, moisture, and nutrients, individuals which are in more favorable situations may grow more rapidly than less favored plants. It is a fairly common practice in experimental work with field crops to discard border rows and ends of plats at harvest, in order to guard against results arising from inequalities in competition. The "competition effect" may be almost negligible when adjacent plats are occupied by varieties or treatments characterized by similar growth habit and may be very great when such varieties or treatments are characterized by great dissimilarity of growth habit. The committee on Standardization of Field Experiments of the American Society of Agronomy, recognizing the danger of introducing serious errors into the results of field experiments by inequalities in competition between adjacent plats, recommended that one row be discarded from each side of a plat for intertilled crops when harvest records were taken.[3] By this precaution a source of error is removed which, in most cases, cannot be determined accurately.

Immer has shown that unbalanced competition between sugar beet brands differing in growth habit is such as to make results obtained

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[1] Contribution from the Division of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Colorado Agricultural Experiment Station. Received for publication January 8, 1934.

[2] Assistant and Associate Agronomist, respectively, Division of Sugar Plant Investigations, U. S. Dept. of Agriculture. Acknowledgment is made to the American Beet Sugar Company for the use of land and facilities at Rocky Ford, Colorado.

[3] WIANCKO, A. T., *et al.* Report of Committee on Standardization of Field Experiments. Jour. Amer. Soc. Agron., 16 : 1–16. 1924.

from one-row plats significantly different from those obtained when three-row plats were used, the outer rows being discarded.[4]

Opportunity was afforded in the agronomic experiments with sugar beets at Rocky Ford and Fort Collins, Colorado, to secure additional evidence of the desirability of discarding border rows to avoid such error. In these experiments the effect of unequal competition was determined for the outside row and also the second border row of the plat.

Results were obtained in 1932 from a date-of-planting study which was being conducted at Rocky Ford and from a variety study at Fort Collins. In the date-of-planting study four dates of planting were used, *viz.*, April 16 (early), May 2 (medium), May 12 (late), and May 21 (very late). The May 21 planting failed to produce a satisfactory stand and was replanted on June 1. Each plat consisted of eight rows, 30 feet in length, with eight plats of each treatment arranged in randomized blocks. The rows were 20 inches wide and the beets spaced 12 inches in the row. At harvest only those beets were taken which had beets adjacent to them in both the same row and the adjacent row. Rows 1, 2, 7, and 8 of each plat were kept separate at harvest but the four inside rows, 3, 4, 5, 6, were put together. In the following discussion, rows 1 and 8 are referred to as the first border rows; rows 2 and 7 as second border rows; and rows 3, 4, 5, and 6 are called the inside rows. As a result of random arrangement and the rejection of certain plats because of poor stand, the number of cases available for determination of the border effect varies from 4 to 40. The average individual weight for the sugar beets in the first border row and in the second border row was compared with the average individual weight for the four inside rows of the plat to secure an index of the competitive effect of the adjoining plat.

In the study conducted at Fort Collins, a wide uncropped alley was left adjacent to a variety experiment, which included seven varieties in four-row plats bordering on the alley. The plats were 40 feet in length. Rows 1, 2, and 3 adjacent to the alley were harvested separately for each plat, only beets with competition on three sides being taken in row 1 and with competition on four sides for rows 2 and 3. Differences were tested for significance by the use of Student's tables as given by Fisher.[5]

RESULTS OBTAINED AT ROCKY FORD

The summarized results obtained at Rocky Ford are presented in Table 1 and shown graphically in Fig. 1.

It is readily seen that the border effect was most pronounced in those cases in which the plats having the widest divergence in planting dates were side by side. Using the 5% point, with P values of .05 or less, as the level of significance, it was found that the yield of the first border rows of the early plats were affected when late or very late plantings were adjacent, and the second border row was also affected when very late plantings were adjacent. The yield of the first border row was influenced significantly in several other comparisons. When late plantings were adjacent to early or medium, the yield of the second border row of the late-planted plats was significantly greater than the average of the four inside rows. The first border row in these late plantings yielded slightly but not significantly less than the inside rows. As a possible explanation it is suggested that the reduction in yield of the first border rows of the late-planted plats, due to competition with early- or medium-planted plats, gave an advantage to the second border rows of the late-planted plats. In the cases in which early-planted plats were adja-

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[4] IMMER, F. R. Varietal competition as a factor in yield trials with sugar beets. Jour. Amer. Soc. Agron., 26: 259–261. 1934.

[5] FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver & Boyd. Ed. 4. 1932.

TABLE 1.—*Summarized data showing border effect influence between different dates of planting of sugar beets, Rocky Ford, Colorado, 1932.*

Adjacent planting	No. of paired comparisons	Ave. root weight in pounds			Difference in % of inside rows*	t	P
		First border row	Second border row	4 inside rows			
Early Planting							
Medium..	16	1.506		1.462	+ 3.01	.7866	Between .5 and .4
Medium..	16		1.455	1.462	— 0.48	.1223	Greater than .9
Late.....	8	1.634		1.338	+22.12	3.6635	Less than .01
Late.....	7		1.419	1.350	+ 5.11	1.8309	Between .2 and .1
Very late.	29	1.838		1.406	+30.73	9.2469	Less than .01
Very late.	28		1.496	1.403	+ 6.63	2.9162	Less than .01
Medium Planting							
Early....	16	1.228		1.300	— 5.54	6.5347	Less than .01
Early....	16		1.314	1.300	+ 1.08	.3847	Between .8 and .7
Late.....	35	1.515		1.320	+14.77	2.9262	Less than .01
Late.....	30		1.337	1.309	+ 2.14	.8403	Between .5 and .4
Very late.	8	1.971		1.350	+46.00	2.7792	Between .05 and .02
Very late.	8		1.384	1.350	+ 2.52	.3614	Between .7 and .6
Late Planting							
Early....	16	1.021		1.064	— 4.04	1.0399	Between .4 and .3
Early....	15		1.198	1.091	+ 9.81	3.2121	Less than .01
Medium..	40	1.079		1.120	— 3.66	1.7360	Between .1 and .05
Medium..	40		1.177	1.120	+ 5.09	3.4356	Less than .01
Very late.	8	1.248		1.142	+ 9.28	1.2668	Between .3 and .2
Very late.	8		1.170	1.142	+ 2.45	.6671	Between .6 and .5
Very Late Planting							
Early....	28	.555		.890	—37.64	11.9445	Less than .01
Early....	29		.806	.890	— 9.44	2.6726	Approaches .01
Medium..	8	.644		1.023	—37.05	7.5739	Less than .01
Medium..	8		.940	1.023	— 8.11	2.5590	Between .05 and .02
Late.....	5	.403		.779	—48.27	12.5923	Less than .01
Late.....	4		.844	.820	+ 2.93	.4195	Between .8 and .7

*The difference in average weight of borders and inside rows is given in percentage of the weight of the four inside rows.

cent to the very late-planted plats, the extreme development of the first border row of the early planting influenced the yield of the second border row of the very late plantings.

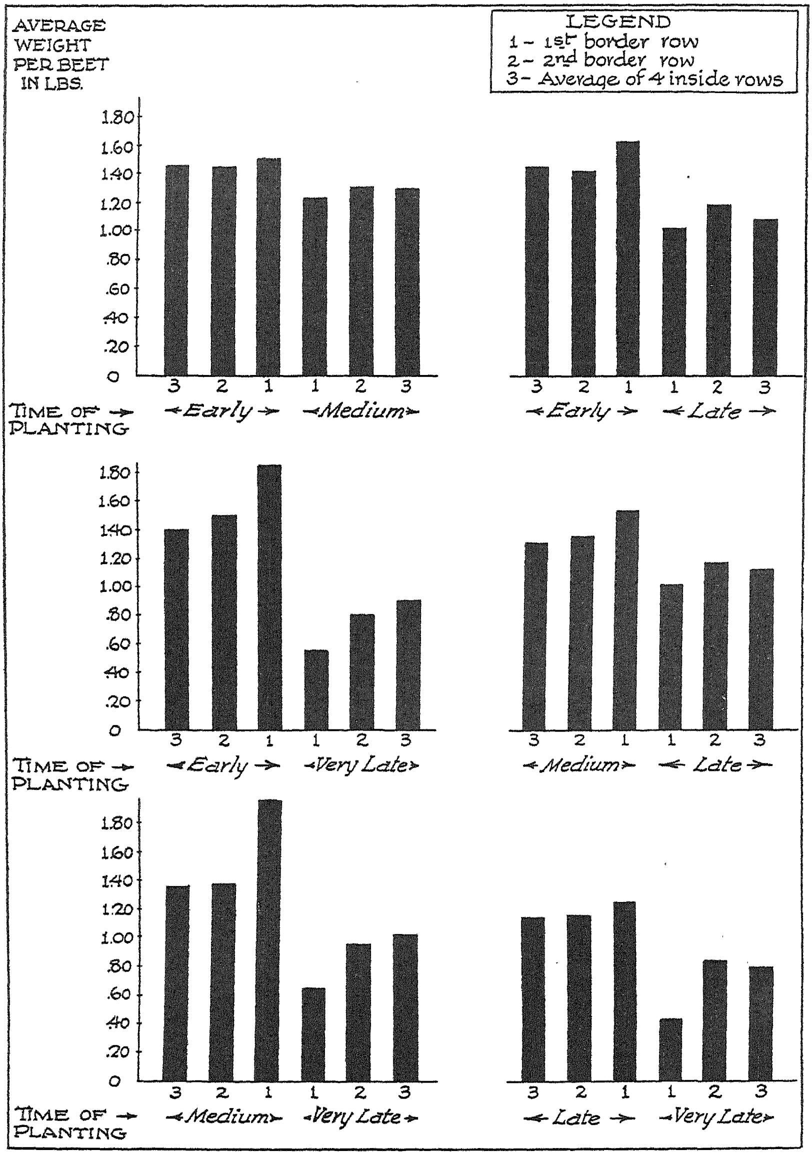

FIG. 1.—Summarized data showing border effect influence between different dates of planting of sugar beets, Rocky Ford, Colorado, 1932.

RESULTS OBTAINED AT FORT COLLINS

In the studies conducted at Fort Collins, the results obtained for the separate plats, each plat representing a different variety, are given in Table 2.

TABLE 2.—*Summarized data showing border effect in studies conducted at Fort Collins, Colorado, 1932.*

Plat	Average weight in pounds per beet		
	1st row	2nd row	3rd row
1	1.32	.90	.98
2	1.25	1.06	.92
3	1.17	.94	.87
4	.74	.85	.61
5	.99	.92	1.04
6	1.03	.78	.73
7	1.22	1.10	.74
Mean	1.10	.94	.84

Comparisons Using t Test of Significance

	t	P
1st row with 2nd row	2.674	Between .05 and .02
1st row with 3rd row	4.034	Less than .01
2nd row with 3rd row	1.469	Between .2 and .1

The yield of the first row is significantly greater than the yield for either the second or the third row. The second row averaged 0.10 pound per beet greater yield than the third row, the odds being between 4 and 9 to 1 that this difference is not due to chance alone.

From these data it appears advisable that when strongly unbalanced conditions of competition between plats are anticipated, enough rows per plat should be provided so that the two outer rows on each side may be discarded.

DISTRIBUTION OF FERTILIZER RESIDUES IN THE SOIL AFTER FOURTEEN YEARS OF A FERTILIZER EXPERIMENT WITH ALFALFA[1]

W. H. Metzger[2]

A fertilizer experiment with alfalfa in continuous culture was started on the agronomy farm of the Kansas Agricultural Experiment Station in the year 1909. The soil is classified as Derby silt loam, a moderately leached soil with a moderately heavy layer, or B horizon, at a depth of 12 to 15 inches. Except for the surface 2 inches of the plat which received lime, none of the samples studied to a depth of 36 inches were calcareous, the highest pH value being 6.9 in the 24 to 36 inch layer of two plats of the series. No fertilizer was applied to any plat previous to seeding or at seeding time in the fall of 1909. The first applications were made as top dressings of manure in the winter and an application of fertilizers in the early spring following the fall seeding. Because of failure to obtain a satisfactory stand, the alfalfa was plowed under in the summer of 1910 and reseeded. Again no fertilizers were applied when the crop was seeded.

After this second seeding the alfalfa stood continuously until the summer of 1923. Encroachment of grasses and weeds made necessary plowing and reseeding at that time. During this period of years, fertilizers and manure were applied annually as top dressings. Since the alfalfa received no cultivation, the fertilizer nutrients applied had no means of penetrating to the lower depths of the soil except by downward movement with percolating ground water or translocation downward in the roots of the plants. Accordingly it was considered desirable to remove soil samples from the plats at various depths previous to the plowing in 1923 to study the distribution of fertilizer residues. This was done and the samples were sealed and stored in mason jars until the analytical work was performed in the winter of 1932–33.

With certain exceptions the conditions of the experiment were favorable for a study of fertilizer movement in the soil. The following exceptions may be noted: (A) The initial fertilizer application was incorporated into the soil to a maximum depth of 4½ to 5 inches by the plowing in 1910. (B) The plat listed hereafter as receiving superphosphate alone received also sodium nitrate, 240 pounds per acre, for each of the first 4 years the experiment was in progress. (C) It is not known how much of each of the plant nutrients were translocated downward in alfalfa roots and thus left at lower levels by decay of such roots prior to the sampling date or how much may have moved downward only to be absorbed by the plants, translocated to the tops, and then removed in the hay. (D) The soil in the series of plats was rather highly variable. An indication of this variability may be obtained by a comparison of the data for the check plats in Tables 3 and 4 or by the slope of the broken line joining the check plats in Fig. 1. In spite of these limitations the samples were considered valuable for such a study.

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[1] Contribution No. 231 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Also presented at the annual meeting of the Society held at Chicago, Ill., November 17, 1933. Received for publication January 9, 1934.

[2] Assistant Professor of Soils. Grateful acknowledgment is hereby extended to Professor R. I. Throckmorton who initiated the project reported here and was responsible for the taking of the soil samples in 1923.

The treatments of the various plats are indicated in Tables 2, 3, and 4, while the rates of fertilizer applications are given in Table 1.

TABLE 1.—*Rates of fertilizer applications.*

Fertilizer	Annual application, lbs. per acre	Total phosphorus (P) applied in 14 years, lbs. per acre	Total potassium (K) applied in 14 years, lbs. per acre
Superphosphate	190	185	
Rock phosphate	380	718	
Sulfate of potash	180* 90†		743
Nitrate of soda	240		
Manure (plats 7, 9, 12)	5,000		
(plat 10)	10,000		
Lime (hydrated)	1,000‡		

*For 6 years.
†For 8 years.
‡Once each 4 years.

In Table 2 are presented the pH values of the soil samples. These values indicate that lime applied as top dressing to plat 12 penetrated the soil to a depth of only 4 to 6 inches. When the values for plat 6 are compared with those for the nearest "no treatment" plats, they suggest movement of the sodium applied as sodium nitrate.

Table 3 and Fig. 1 show the easily soluble phosphorus at various depths in the soil at the close of the 14-year period. The phosphorus was extracted with 0.2 N HNO_3 at a soil-solution ratio of 1 : 10, with shaking for 30 minutes on a mechanical shaker. The color was developed in an aliquot of the extract by the method described by Benedict and Thies (1)[3] in which reduction is accomplished by addition of a solution of sodium bisulfite and hydroquinone. This method was preferred to certain others because the color developed is relatively stable.

The outstanding points of interest in the phosphorus data may be briefly summarized as follows:

1. There was considerable accumulation in the surface 0–2 inches and relatively little movement of phosphorus where superphosphate was applied alone. This conclusion was reached by assuming a continuous increase of easily soluble "native" phosphorus from plat 5 to plat 1, as indicated by the broken line in Fig. 1. The topographic position of the plats and the data for plats 2 and 5 make this assumption appear valid. Perhaps there might have been even less movement indicated had sodium nitrate not been applied with the superphosphate the first 4 years of the experiment.

[3] Figures in parenthesis refer to "Literature Cited," p. 625.

TABLE 2.—*The pH values* of the soil at various depths under variously treated alfalfa plats.*

Depth in inches	Plat 1, superphosphate	Plat 2, no treatment	Plat 3, superphosphate, K_2SO_4	Plat 4, K_2SO_4	Plat 5, no treatment	Plat 6, superphosphate, K_2SO_4, $NaNO_3$	Plat 7, manure 2.5 tons, rock phosphate	Plat 8, no treatment	Plat 9, manure 2.5 tons	Plat 10, manure 5 tons	Plat 11, no treatment	Plat 12, manure 2.5 tons, lime
0–2	5.0	5.6	5.4	5.6	5.8	5.7	5.7	5.8	5.5	5.6	5.7	7.0
2–4	5.7	5.7	5.5	5.7	5.7	6.2	5.7	6.0	5.4	5.5	5.7	6.2
4–6	5.8	5.8	5.7	5.8	5.7	6.3	5.7	6.2	5.4	5.4	5.6	6.0
6–9	5.8	5.7	5.7	5.8	5.7	6.5	5.7	6.1	5.3	5.2	5.7	5.8
9–12	5.8	5.8	5.8	5.8	5.8	6.6	5.8	6.2	5.4	5.4	5.8	5.8
12–18	5.6	5.7	5.7	5.7	6.3	6.6	6.1	6.3	5.6	5.6	5.8	5.8
18–24	5.8	5.9	5.9	6.0	6.5	6.7	6.3	6.7	5.8	5.8	6.0	6.1
24–36	6.3	6.3	6.3	6.2	6.9	6.8	6.8	6.9	6.0	6.0	6.2	6.3

*Determined with the quinhydrone electrode.

TABLE 3.—*Easily soluble phosphorus in the soil of variously treated alfalfa plats expressed in parts per million of air-dry soil.*

Depth in inches	Plat 1, superphosphate phate	Plat 2, no treatment	Plat 3, superphosphate, K_2SO_4	Plat 4, K_2SO_4	Plat 5, no treatment	Plat 6, superphosphate, K_2SO_4, $NaNO_3$	Plat 7, manure 2.5 tons rock phosphate	Plat 8, no treatment	Plat 9, manure 2.5 tons	Plat 10, manure 5 tons	Plat 11, no treatment	Plat 12, manure 2.5 tons, lime
0–2	116.9	25.0	60.0	18.1	13.7	92.7	162.4	18.7	32.5	54.1	17.5	38.7
2–4	21.9	17.5	18.1	13.7	8.1	16.2	92.6	10.0	9.4	10.0	10.0	10.0
4–6	26.2	17.5	15.6	11.9	7.5	13.7	39.4	10.0	9.0	8.7	8.7	9.0
6–9	15.0	15.6	16.2	9.4	6.2	13.7	28.7	9.4	10.0	7.5	6.9	8.0
9–12	13.8	14.4	15.6	8.1	5.0	18.7	25.6	9.4	7.5	10.0	5.0	6.0
12–18	17.8	12.7	7.5	4.5	13.5	26.2	20.0	9.4	5.2	6.7	11.6	5.2
18–24	32.4	21.2	11.6	2.5	17.5	20.6	57.5	28.7	13.7	13.7	12.0	17.5
24–36	51.2	42.5	13.5	18.4	36.5	63.3	50.0	57.5	35.0	40.0	41.2	42.5

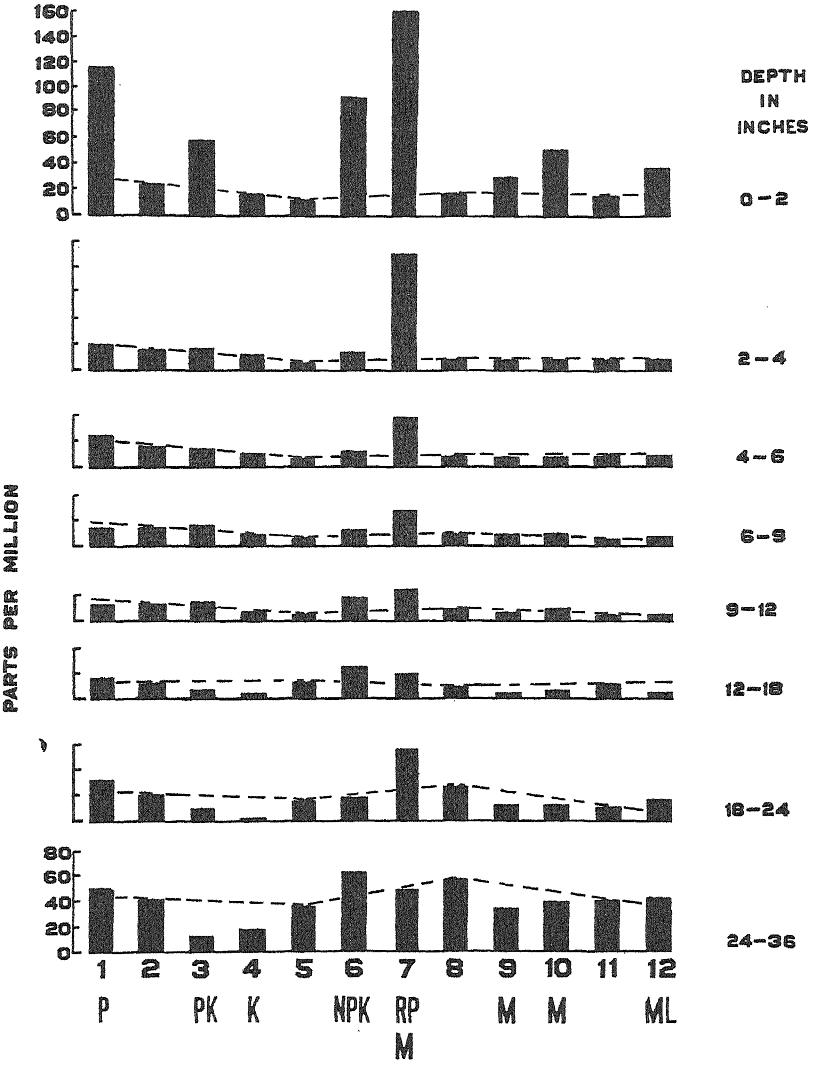

FIG. 1.—Easily soluble phosphorus under an old alfalfa sod.

2. Less phosphorus accumulated at the surface where potash accompanied superphosphate than where superphosphate was applied alone and less phosphorus was found low in the profile than in adjoining "no treatment" plats. Apparently potash had one of three possible effects, *viz.*, (a) it stimulated absorption and removal of phosphorus by the alfalfa plants, (b) it rendered it less easily

soluble, or (c) it caused it to be leached below the 36-inch level. Of these, the first appears to be the most logical conclusion. This question is now being studied further.

3. Movement of phosphorus is indicated throughout the profile in the complete fertilizer plat. It is probable that this phosphorus moved in combination with sodium from the sodium nitrate. This type of movement has been demonstrated by Dyer (2), Midgley (3), and others.

4. Phosphorus movement is strikingly apparent where rock phosphate was applied, a result in accordance with that reported by Thor (5).

5. Practically no accumulation of phosphorus below the 2-inch level is indicated in any of the manure plats, and therefore the movement of phosphorus in the rock phosphate and manure plat must have applied to the rock phosphate rather than to the phosphorus in the manure. Significant movement of phosphorus from manure has been reported by Dyer (2) and by Stephenson (4), but in their experiments the manure was incorporated with the plowed layer.

One must bear in mind when the rock phosphate plat is compared with plats receiving superphosphate that nearly four times as much phosphorus was supplied by the rock phosphate treatment as was carried by each of the superphosphate treatments.

Table 4 shows the exchangeable potassium in the soil at various depths for the first six plats of the series, which includes all plats receiving potassium-carrying fertilizer. The potassium was replaced by a continuous leaching method in which 0.05 N HCl was used. These data show, briefly, the following points of interest:

1. Movement of potassium as indicated by accumulations below the surface 2 inches was limited to about the surface 9 or 12 inches.

2. Apparently more of the applied potassium was utilized by the plants on the plats where complete fertilizer was used than on the plat where only superphosphate accompanied the potash or on the plat where potash was applied alone.

3. The data indicate that in plat 4, treated with K_2SO_4 alone, slightly more than one-half the applied potassium remained as a residue in the surface 6 inches of soil.

TABLE 4.—*Exchangeable potassium in the soil of variously treated alfalfa plats expressed in milligram equivalents per 100 grams of soil.*

Depth in inches	Plat 1, superphosphate	Plat 2, no treatment	Plat 3, superphosphate, K_2SO_4	Plat 4, K_2SO_4	Plat 5, no treatment	Plat 6, superphosphate, K_2SO_4, $NaNO_3$
0–2....	2.19	1.71	2.46	2.39	1.37	2.50
2–4....	1.06	1.30	1.85	2.26	1.23	1.50
4–6....	0.99	1.03	1.09	1.16	0.96	0.86
6–9....	1.06	1.06	1.33	1.47	1.13	1.03
9–12...	1.09	1.50	1.57	1.09	0.89	0.82
12–18...	1.16	1.23	1.09	0.89	0.86	0.86
18–24...	1.32	1.24	1.14	1.08	1.00	0.87
24–36...	1.03	0.96	0.86	0.86	0.82	0.79

4. Finally, this soil is abundantly supplied with potassium, making the measurement of such small differences as would result from slight movement very difficult or impossible.

The annual rainfall at Manhattan averages about 31 inches and of this amount nearly three-fourths falls during the 6 months period of April to September. The high evaporation rate during that period of the year and the high water requirement of a crop such as alfalfa placed a decided restriction on ground water penetration in the soil under this alfalfa sod. Greater movement of fertilizer nutrients might occur under conditions which would admit of deeper penetration of rainwater into the soil profile.

SUMMARY

Soil samples taken at various depths from the plats of a 14-year-old alfalfa stand were analyzed to determine the distribution of phosphorus and potassium residues from annual top dressings of various fertilizers.

Phosphorus from superphosphate accumulated in considerable amount at the surface but penetrated the soil only in small amounts where applied alone. Less easily soluble phosphorus was found low in the profile of plats treated with superphosphate and K_2SO_4 and with K_2SO_4 alone than in "no treatment" plats. Marked movement of phosphorus was indicated where rock phosphate was applied. Movement was also noted where a complete fertilizer including $NaNO_3$ was used.

Potassium movement was not marked in any case and was limited to the surface 9 to 12 inches. Where K_2SO_4 was applied alone slightly more than one-half the potassium applied remained as a residue in the surface 6 inches. It was more completely utilized by the alfalfa when applied with other fertilizer salts.

Surface applied lime penetrated the soil only about 6 inches during the 14-year period.

LITERATURE CITED

1. Benedict, Stanley R., and Thies, Ruth C. A modification of the molybdic method for the determination of inorganic phosphorus in serum. Jour. Biol. Chem., 61 : 63–66. 1924.
2. Dyer, B. Results of investigations on the Rothamsted soils. U. S. D. A. Off. Exp. Sta. Bul. 106. 1902.
3. Midgley, A. R. The movement and fixation of phosphates in relation to permanent pasture fertilization. Journ. Amer. Soc. Agron., 23 : 788–798. 1931.
4. Stephenson, R. E., and Chapman, H. D. Phosphate penetration in field soils. Jour. Amer. Soc. Agron., 23 : 759–772. 1931.
5. Thor, A. U. The availability and downward movement of rock phosphate in Illinois soils when used liberally for 25 to 30 years and influence of the treatment on available potash and total nitrogen. Jour. Amer. Soc. Agron., 25 : 661–673. 1933.

NOTES

AN EQUIPMENT FOR DEMONSTRATING SOIL EROSION AND ITS CONTROL

On two occasions recently the writer has set up an exhibit which would call the attention of farmers to the devastating results of erosion and suggest some control measures. An equipment was devised which functioned admirably, not only in portraying the lesson but also in attracting and holding the attention of visitors long enough for them to grasp its importance.

The equipment consists of a rack to hold several erosion trays at any desired slope, trays in which various soils or cover crops may be compared, and carboys to receive the turbid runoff. The rack is made of 2 by 4 inch uprights and cross pieces, braced with 1 by 4 inch material (Figs. 1 and 2). The total height is 7 feet, the shelf being 3½ feet from the floor. Good quality smooth roofing paper is attached to the back, shelf, and front so that any spray which escapes the trays will flow into the carboy trough. This paper is lapped, as shown in Fig. 2, so that no water will leak through to the floor.

A trough to support the carboys and to receive any water flowing from the shelf is supported 12 to 15 inches from the floor. This trough is 12 inches wide and its sides are 4 inches deep. It is closed on both ends. It has a tube in the bottom by which all drainage water is led off through a flexible fire hose. The trough is water tight, having been made so by first painting the lumber on all sides with

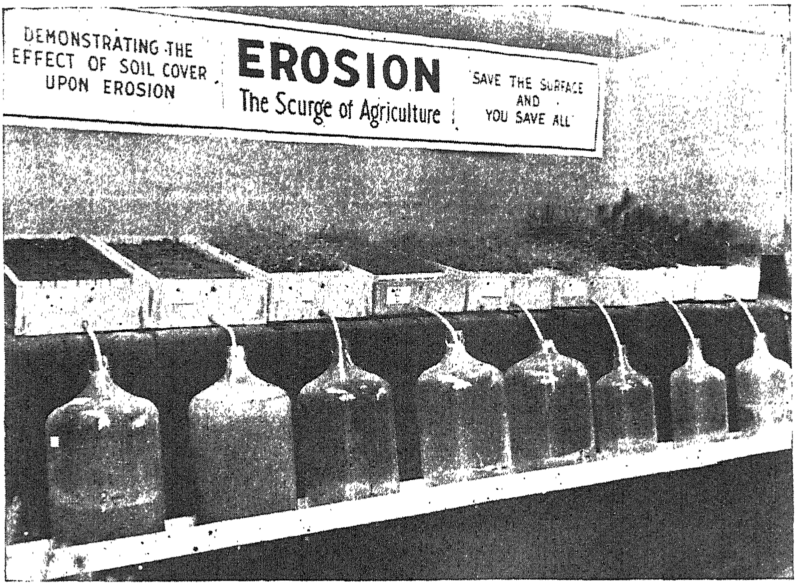
DEMONSTRATING THE EFFECT OF SOIL COVER UPON EROSION
EROSION
The Scurge of Agriculture
SAVE THE SURFACE AND YOU SAVE ALL

FIG. 1.—Equipment for demonstrating the effect of soil cover upon erosion.

white lead paint and protecting the corners with three-cornered strips set in paint. It slopes gently toward the outlet.

The individual trays are 4 inches deep, 12 inches wide, and 32 inches long. A dam with beveled edge is placed 3 inches from the lower end, thus providing a place for the surface run-off to collect so that it may be led by means of the rubber tubing into the carboy. In Fig. 1, tray No. 6 shows the dam most distinctly. In the bottom of each tray, 15 3/8 inch holes were made to insure good drainage, in other words it was desired to show that the condition of the surface determines in a large measure the erosiveness. The trays were painted inside and outside. In this setup eight such trays were used.

The carboys used to receive the surface run-off were of 5-gallon capacity. The attention of visitors is immediately attracted by the fact that the bare soils produce much run-off and that it is turbid, while soils well covered with vegetation produce but little run-off which is clear. As the carboys become filled they are emptied into the trough.

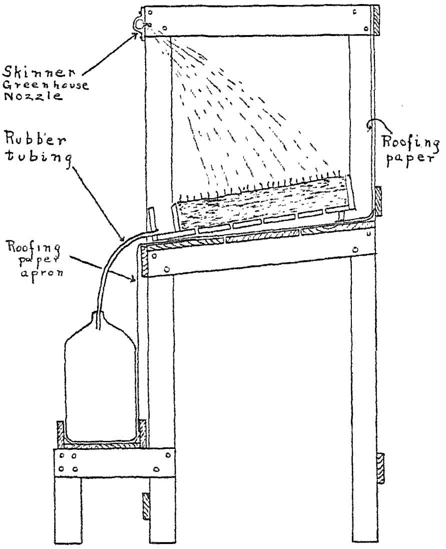

FIG. 2.—Sectional view of erosion demonstrator, showing how roofing paper is lapped to deliver drainage water into trough. The location of pipe and nozzles is also shown.

A ¾ inch galvanized pipe spans the front of the frame, being held to the uprights with straps. Along this pipe at intervals of 2 feet are spaced Skinner greenhouse nozzles designed to give a very fine spray. Those afford a very uniform distribution of "rain" over all trays. One end of this pipe is capped, while the other end has a globe valve and is connected to a garden hose. It is neither necessary nor desirable to keep the sprinkler in operation continuously. It is sufficient to turn it on occasionally, simulating occasional showers. Incidentally, it was found instructive to show how quickly surface run-off takes place on the unplanted trays after sprinkling begins.

With the equipment as described it is possible to make several comparisons. One may compare soils of varying textures or structures. One may compare one slope with another or the influence of soil cover upon erosion. In the demonstration shown in Fig. 1, the following comparisons were made, all on the same soil series: (1) Bare subsoil; (2) bare surface soil; (3) rape cover crop, 7 weeks old; (4) rye and vetch cover; (5) crimson clover cover; (6) timothy, 7 weeks old; (7) old bluegrass sod; and (8) section of forest floor. Although the "rainfall" was practically equal on all trays, the run-off from the bare subsoil (1) filled the carboy several times with a very turbid clay suspension. The run-off from the bare surface soil (2) was much less and much clearer. The remaining trays, although in four cases the cover crops were only 7 weeks old, produced less than a gallon of run-off during the 5 days the exhibit was in operation. The old bluegrass sod and the forest litter allowed practically no run-off. (The carboy under No. 8 had an alkali etching about one-half way from the bottom, but it contained only about a pint of run-off.)

The rack is put together with screws and bolts. It may be knocked down and shipped in small bulk. It is quite inexpensive, costing about $35.00 for materials and labor.—F. G. MERKLE, *Pennsylvania State College, State College, Pa.*

FURTHER STUDIES ON THE INFLUENCE OF THE CARBON-NITROGEN RATIOS OF ORGANIC MATTER ON RATE OF DECOMPOSITION IN THE SOIL

In the April, 1934, number of this JOURNAL an article appeared entitled "The Influence of the Carbon-Nitrogen Ratios of Organic Matter on the Rate of Decomposition in the Soil," by I. J. Hutchings and Thomas L. Martin. The work reported consisted of three parts as follows: 1. The organic materials (alfalfa and sweet clover roots and tops and wheat straw) were incorporated with the soil, incubated for 30 days, and the decomposition measured by the amount of CO_2 evolved and the amount of NO_3 accumulated. 2. The C-N ratios were all narrowed to 10:1 by the use of $NaNO_3$ and the experiment repeated. 3. The C-N ratios were all widened to 80:1 by the use of cellulose and the same procedure followed.

It was found in part I that the organic materials decomposed in the following order: Sweet clover tops, alfalfa tops, sweet clover roots, alfalfa roots, and straw. In part II, even though the C-N ratios were equivalent, the rate of decomposition was not changed. Similar results were obtained in part III.

The conclusion drawn by the writers was as follows: "That the narrowing of the C-N ratio to 10:1 and widening it to 80:1 by the means of $NaNO_3$ and cellulose, respectively, using alfalfa tops and roots, sweet clover tops and roots, and wheat straw, influenced very little the relative rates at which these materials decomposed as measured by CO_2 evolution and NO_3 accumulation. These facts indicate that the chemical composition of the material is a very important factor to be considered when discussing the rate at which organic matter will decompose."

The period of incubation was 30 days. It appeared that a stage of equilibrium in decomposition was approached at about the 15-day period, the CO_2 evolution for all materials seemed to become more or less uniform, and the NO_3 accumulation started to rise. It was thought that the experiment should be run for a 60-day period to see whether or not the conclusions drawn by Hutchings and Martin in the 1 to 30-day period were justified. Therefore, the investigation was continued and determinations made daily during the 30 to 60-day period.

The results of the investigation indicate that in all cases the amount of CO_2 evolved at about the 15-day period was found to be fairly constant daily to the end of 60 days, even though the C-N ratios were normal, narrowed, or widened. Also, the nitrates that began to accumulate at the end of 15 days kept up their steady increase to the end of the 60-day period. It would appear from this that Hutchings and Martin were justified in claiming that equilibrium in decomposition was very closely reached at approximately the 15-day period of incubation.

These writers explained that in all probability the 15-day period was the time when most of the available energy had been decreased to the point where bacterial activity was much retarded, resulting in little use for the NO_3 and thus permitting the NO_3 to accumulate and CO_2 evolution to diminish. The present writers checked this point by adding dextrose at the time when the NO_3 started to accumulate and the CO_2 had decreased considerably. The result was that in 2 days the CO_2 evolution rose and the NO_3 accumulation decreased to 0. This would justify the conclusions drawn by the first experimenters.

The thought also occurred that perhaps the narrowing of the C-N ratio with water-soluble extracts of the materials would be more nearly natural than using $NaNO_3$ for that purpose. This was done. The results were approximately the same as previously when $NaNO_3$ was used. The CO_2 evolution was more vigorous and the accumulation of NO_3 was more intense. The straw showed considerably more activity because of the increased amount of available energy. The relative rates of decomposition, however, were approximately the same.

From these experiments it would appear that Hutchings and Martin were justified in their conclusions drawn in the article referred to above.—T. B. HUTCHINGS and T. L. MARTIN, *Department of Agronomy, Brigham Young University, Provo, Utah.*

A NEW TYPE OF NURSERY THRESHER

A nursery thresher that threshes and separates grain at a possible rate of more than 150 rod-row bundles an hour has been constructed at the Washington Agricultural Experiment Station, Pullman, Wash. This thresher (Fig. 1) is a combination of an overshot cylinder and a modified screenless shaker and fan of an ordinary fanning mill.

During the threshing operation the nursery bundles are fed into the cylinder gradually to break up the straw. When the straw is long the butts of the bundles are thrown aside, but otherwise the entire bundle passes through the machine. The threshed grain, including straw and chaff, falls on the shaker, which tosses the material into an air chute or venturi. The grain and some of the heavier particles fall through the air current into a pan, while the straw and chaff are blown over the tailings board. The grain is further cleaned by a separate recleaner, which consists principally of a shallow ¼-inch mesh screen box over a fan. The recleaning can be done while another sample is being threshed.

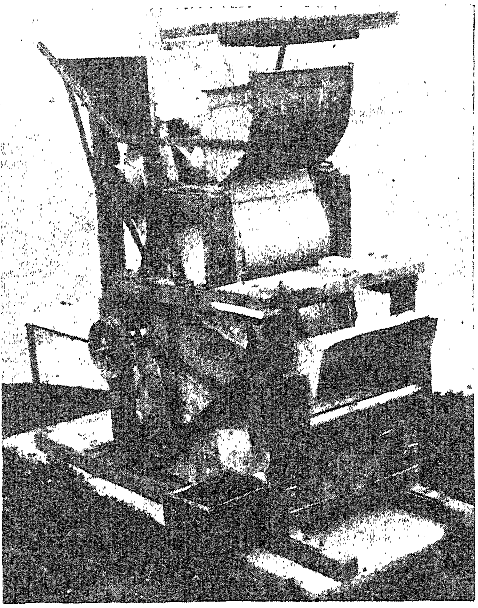

FIG. 1.—Rod-row thresher showing concave section open.

The thresher is designed for self-cleaning by gravity. Tilting the feeding table forces all loose material to slide into the feed chute. The concave section can be opened with a lever while the machine is in motion.

The thresher has been used successfully for the last two seasons by the Washington Agricultural Experiment Station and the Pacific Northwest Soil Erosion Station at Pullman, Wash. Wheat, oats, barley, peas, flax, and a number of grasses have been threshed.—O. A. VOGEL, *Division of Cereal Crops and Diseases*, *Bureau of Plant Industry*, and ARTHUR J. JOHNSON, *Pacific Northwest Soil Erosion Station, U. S. Dept. of Agriculture.*

AGRONOMIC AFFAIRS

NEWS ITEMS

F. J. SIEVERS, Director of the Massachusetts Agricultural Experiment Station and of the Graduate School at Massachusetts State College, has been elected by the United States Trust Company of New York to direct the investigations under the Herman Frasch Foundation for Chemical Research. Research in agricultural chemistry under this Foundation is at present being supported at the University of Wisconsin, the University of Missouri, and the Boyce Thompson Institute.

AN AGRONOMIST with considerable field and laboratory experience in soils and in plant breeding and with an M. S. degree from the University of Minnesota with a major in agronomy and a minor in plant pathology, is seeking a connection for teaching or research. For further information, write to the Editor of this JOURNAL.

THREE RECENT publications from the U. S. S. R. of interest to agronomists include "Plant Industry in the U S. S. R.;" "Seed Growing," official journal of the state all-union seed federation; and "Agricultural Turkey." Further details regarding each of these publications may be obtained from J. W. Pincus, Consulting Agriculturist, 308 West 94th Street, New York City.

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EXPERIMENTAL ERROR IN FIELD EXPERIMENTS WITH PINEAPPLES[1]

O. C. MAGISTAD and C. A. FARDEN[2]

Improvement in agricultural practices of the pineapple industry rests, to a large degree, upon careful and adequate field experiments. In such a program the determination of the magnitude of the field error, the optimum plat size, and the number of replications requiring the minimum expense and trouble are important.

Mercer and Hall (3),[3] who in 1910 published an excellent article on uniformity trials, were among the first to make a critical study of yield variation and its bearing on experimental technic. They found that with a sufficiently large number of plats, the distributions of yield and other measurable characters of the crop grown tended to be normal in form. Many more recent investigators have confirmed the presence of a normal distribution.

One of the most exhaustive investigations of this type is that of Demandt (1), who in Java in 1931 harvested 203 blank experiments with sugar cane, each consisting of 36 plats. Not only were yields of cane obtained but sugar content as well. The distribution of yields was normal in character. Thus, on the basis of cane weights, considering each experiment to consist of two blocks of 18 replications each, 96, or 47% of the total, fell in the group where the difference between the two blocks was less than 1% of the mean yield. He demonstrated that occasionally the difference between "treatments" in a blank experiment is very great as would naturally follow from the normal distribution curve.

The present article contains data relating to field experiments with pineapples, gives estimates of the experimental error under various conditions, and suggests how field experiments can be improved.

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[1] Technical paper No. 66 of the Experiment Station of the Pineapple Producers Cooperative Association, Honolulu, Hawaii. Received for publication January 22, 1934.

[2] Chemist and Assistant Chemist, respectively. The authors wish to express their appreciation to the California Packing Corporation and to Libby, McNeill & Libby for permission to conduct these experiments, and to Dr. M. B. Linford and Mr. N. King of the Pathology and Agriculture Departments, respectively, for aid in securing some of the data.

[3] Figures in parentheses refer to "Literature Cited," p.643.

NATURALLY OCCURRING FIELD VARIATION

Under the heading "What do Field Tests Mean?", W. A. Wendt and A. L. Dean published locally results obtained by weighing separately pineapple fruits from 14 beds. Weights of fruit varied from 1,698 to 2,391 pounds per bed. The conclusion was reached that considerable variation between beds does occur, that this variation is reduced somewhat by combining several beds, and that average fruit weights are less variable than total weights.

In 1930, 100 individual fruits were weighed to the nearest gram. These fruits were obtained in a single picking from two and one-half beds. The range in weight was from 1,533 to 3,560 grams with a mean of 2,692 grams and a standard deviation of 370.5 grams. In the case of a normal distribution of a large number of fruits two-thirds will fall between the mean minus the standard deviation and the mean plus the standard deviation. In our case we could expect 67 fruits to fall between 2,321 and 3,062 grams. Actually the number was 71, a close agreement with the expected.

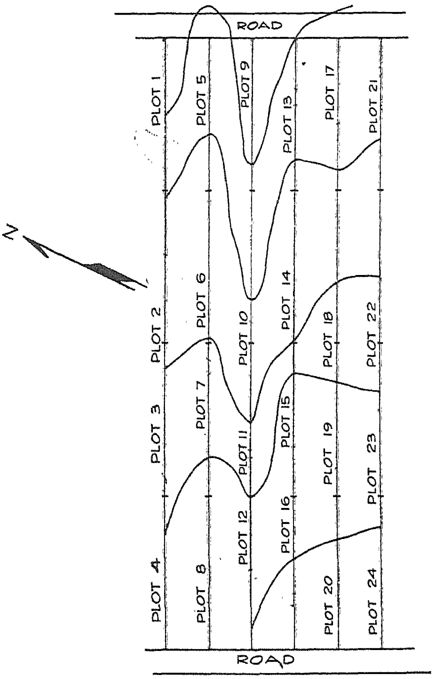

FIG. 1.—Design of blank test in C. P. C. Field 19, Kunia.

During the summer of 1932 additional evidence was obtained on yield uniformity in small adjacent plats in three contrasting regions of the island of Oahu, namely, Kunia, Pearl City, and Kahuku. This work was combined with investigations on fruit quality in these same areas and the data were obtained by the Chemistry and Pathology Departments cooperating.

BLANK TEST, FIELD 19, KUNIA

In this field, harvested in 1932, there were four rows per bed. A 300-foot bed was divided into four equal parts to form plats 1, 2, 3, and 4. The third bed from this was similarly divided to form plats 5 to 8, inclusive. In the same manner plats 9 to 24 were formed. In this way 24 plats each 75 feet long and 1 bed wide were formed. A diagram of plat distribution in this blank test is shown in Fig. 1

Small areas in Fig. 1 enclosed by dotted lines represent spots in which the plants were wilted. The wavy heavy lines are 1-foot contour intervals. The experimental area was therefore about 4 feet higher on the west side than on the east, with a depression in plats 9 to 12, inclusive.

At the time this blank experiment was laid out it was believed that plats less than 75 feet long would be impractical. Subsequent results have proved that the plats should have been much smaller. They then could have been grouped to form larger units.

RESULTS OBTAINED

Fruits, when ripe, were harvested and weighed separately to the nearest 20 grams. A summary of the results obtained is shown in Table 1.

TABLE 1.—*A summary of fruit numbers and mean weights by plats in blank experiments in fields 19, 21, and 82, all weights in grams.*

Plat No.	Field 19		Field 82		Field 21	
	Number	Mean weight	Number	Mean weight	Number	Mean weight
1......	152	2,116	227	1,236	144	2,149
2......	171	2,059	233	1,245	169	2,147
3......	174	2,340	232	1,301	164	2,221
4......	172	2,136	181	1,122	160	2,052
5......	164	1,904	174	1,223	137	2,015
6......	184	2,030	232	1,262	169	1,973
7......	183	2,256	235	1,210	171	2,216
8......	171	2,254	195	1,303	128	2,363
9......	178	1,963	232	1,285	179	2,021
10......	189	2,022	220	1,268	184	2,042
11......	187	2,024	227	1,275	189	1,762
12......	174	2,028	238	1,286	203	1,985
13......	159	1,950	234	1,182	149	2,152
14......	183	2,103	214	1,200	192	2,007
15......	178	2,076	228	1,266	154	2,100
16......	167	2,005	219	1,230	162	2,017
17......	164	2,084	221	1,221	193	2,000
18......	174	2,125	229	1,308	184	1,987
19......	181	2,219	209	1,194	194	1,859
20......	177	2,121	214	1,307	180	1,966
21......	145	2,081	220	1,383	174	2,061
22......	177	2,167	222	1,302	172	2,159
23......	151	2,244	231	1,353	171	1,978
24......	153	2,099	231	1,386	178	2,112
25......					179	2,076
Total..	4,108		5,298		4,279	
Mean..		2,101		1,266		2,057

An examination of the mean weight column for field 19 in Table 1 shows that large variation, ranging from 1,904 to 2,340 grams, exists between the mean yields of the various plats. Such variation between plat yields emphasizes the heterogeneous character of the soil, which is one of the greatest sources of error in field experimentation.

The weights of individual fruits for a few randomly selected plats found in Table 1 were assembled and plotted in a frequency diagram. The distribution of the yields was found to approach very closely the normal curve. Only with normal distribution can the mathematics of normal distributions be used, otherwise corrections for skew are necessary.

EFFECT OF PLAT SIZE ON RELIABILITY OF MEAN YIELD

In order to obtain evidence on the validity of mean yields for plats of various sizes, new plats have been formed by various groupings of the original 24 plats. In each case the standard deviation of this new unit was calculated and expressed as a percentage of the mean. This places the values on a more comparable basis. The results are given in Table 2.

TABLE 2.—*Effect of plat size on accuracy of yield data in field 19, standard deviation of a single plat as percentage of the mean.*

Length of beds in feet	Beds					
	1	2	3	4	5	6
75	5.05	4.77	3.59	(3.88)*	(3.42)	3.47
150	4.48	4.50				
225	(3.37)					
300	3.62					

Number of Replications for a Significance of 5% of the Mean

$$\left[N = \left(\frac{2 \times 1.414 \times \sigma x}{5}\right)^2\right]$$

Length of beds in feet	1	2	3	4	5	6
75	8.2	7.3	4.1	(4.8)	(3.7)	3.9
150	6.4	6.5				
225	(3.6)					
300	4.2					

*Figures in parentheses are standard deviation obtained from data of part of entire area.

The figure 5.05 is the standard deviation for a single plat one bed wide and 75 feet long. Further to the right, the figure 3.59 represents the standard deviation in percentage for a plat three beds wide, 75 feet long, and determined when the yields of plats numbered 1, 5, and 9 were combined into one plat; numbers 2, 6, and 10 into another; numbers 3, 7, and 11 into another; etc. In this manner standard deviations for seven different combinations, involving the use of yields from all 24 plats, were obtained. The figures in parentheses in the table indicate that the combinations were such that several plats had to be omitted. For example, the figure 3.37 (Table 2) is the standard deviation for a plat whose size was one bed wide and 225 feet long. This was obtained by combining the yields of plats numbered 1, 2, and 3 into one plat; numbers 5, 6, and 7 into another; numbers 9, 10, and 11 into another; etc., and that weights of plats numbered 4, 8, 12, 16, 20, and 24 were omitted from the combinations.

In general, the standard deviation in percentage of the mean decreased with increased size of plat. Increasing the width of the plat from 1 bed to 6 beds and 75 feet long resulted in a decrease in standard deviation of only 1.58%; while increasing the length of the plat from 75 feet to 300 feet and 1 bed wide has resulted in a decrease of the standard deviation of only 1.43%.

In a comparison of two treatments, we can have 12 replications using the smallest sized plat or we can choose to have 6 replications, using plats twice as wide or long. According to the values in Table 2, 12 replications with the smallest sized plats clearly will give us the greatest accuracy, but this may entail too much labor or a greater degree of accuracy than necessary.

On the other hand, let us compare four treatments each having six replications. Using the smallest sized plats, roughly 75 by 6½ feet, we have a fairly accurate experiment. If we decide to have plats twice as large, the experiments cannot be installed in the area from which our data were obtained. Increasing the area of the experiment places the replications of a treatment at greater distances from the center, with greater chances for soil variability. Under this condition the values for the larger sized plats recorded in Table 2 tend to be smaller than would happen in practice. The values given in Table 2 show that almost as great an accuracy can be obtained from plats 75 feet long and one bed wide, as from plats of large dimensions. This indicates that probably many of our older experiments in which large areas were devoted to a few treatments were uneconomical.

INFLUENCE OF REPLICATION

By replication of plats receiving the same treatment it is possible to reduce the standard error of the treatment. If this error can be reduced to a relatively low level with respect to a small actual difference in yield between different varieties, or occasioned by different treatments to the same variety, it permits us to obtain results which can be considered reliable and reproducible. From a study of the normal distribution of events, statisticians have found that if "N" randomly selected plats each having "n" fruits can be obtained from a large population, then the standard deviation of the arithemtic means of the plats of "n" fruit weights approaches as a limit the equation $\sigma_m = \frac{\sigma_x}{\sqrt{n}}$. In this formula σ_x is the standard deviation of all the fruits in the population, not the standard deviation of the fruits in a random sample, and σm is the standard deviation of the arithmetic means of all samples, or the standard error. Inasmuch as it was shown that the fruit yields of our experiment were normally distributed, we are justified in using the formula just proposed because our estimated standard deviation tends to approach the true standard deviation of the population as the number of plats is increased. It is this formula which enables us to determine the number of replications necessary to obtain a certain accuracy.

If we wish to reduce the standard error of the treatment from 5% to 2% of the mean, substitution in the formula will show that we need approximately six replications to bring about this reduction. This formula shows us how many replications are normally necessary to demonstrate that a predetermined small difference shall be found to be a reliable or significant one. Under present conditions the standard deviation of a single plat is equal to about 5% of the mean. By employing the above equation we can readily see that about 50 replications over a small area would be necessary in order that a 2% difference in yield between two treatments could be found to be "significant". By "significant" we imply that the difference between the means of two treatments is such that in 19 trials out of 20, treatment A would be found superior to treatment B. This happens when the difference between the treatments is at least twice the standard deviation of the difference of these treatments.

We have decided to adopt a standard error of 5% of the mean as the minimum level of statistical significance. This is equivalent to reducing the errors to 1.77% of the mean. On this basis, by substituting the proper figures in the formula $N = \left[\frac{2 \times \sqrt{2} \times \sigma_x}{5}\right]^2$, we can readily calculate the number of replications for the different plat sizes. The results of this calculation appear in the lower half of Table 2. It will be observed from the table that with eight replications of plats one bed wide and 75 feet long, a difference between yields of treatments exceeding 5% of the mean could be considered significant. Similarly, this accuracy could be obtained with four replications from plats 3 beds wide and 75 feet long, provided the experimental area was not increased. While the figures in this table suggest many ideas as to how large a plat one should properly use in conducting an experiment, this phase of the subject will be discussed later.

In this blank test there is a rapid decrease in replications necessary when passing from plats one bed wide to plats three beds wide. Beyond this the number of replications which are necessary change slowly. Increasing plat length beyond 150 feet reduces error but slightly.

BLANK TEST FIELD 82

In the blank test in field 82 at Pearl City, there were four rows per bed. Eight beds, each separated by two beds, were selected and harvested. Beds were 8 feet center to center. Each bed was divided into three plats 76 feet long. This plan supplied 24 plats from which six combinations of plat sizes were obtainable for the evaluation of their standard deviations. The field had a southwesterly exposure, with the northeast end about 13 feet higher than the southwest end. The rows ran in the north-south parallel. Mean fruit weights for all plats are recorded in Table 1. The standard deviations of the various plat sizes are found in Table 3.

The standard deviations per plat 76 feet long decrease very slowly as the plat size varies in width from one to six beds. On the other hand, for plats one bed wide, the errors decrease very rapidly as the length of the plats increases from 76 feet to 228 feet. However, for plats two beds wide with varying lengths, the errors decrease very slowly. An unusually low error was obtained with plat sizes one bed wide and 228 feet long when compared with errors for other plat sizes. This seems to be accidental. The number of replications

TABLE 3.—*Effect of plat size on accuracy of yield data in field 82, the standard deviation of a single plat of size indicated given in percentage of the mean weight*

Length of beds in feet	Beds							
	1	2	3	4	5	6	7	8
76	4.97	4.53	(2.99)*	3.53	(3.10)	(3.08)	(3.71)	3.63
152	(3.87)	(3.32)						
228	1.67	3.29						

*Figures in parentheses are standard deviation obtained from data of part of entire area.

necessary to demonstrate a significant increase in yield of 5% can be calculated as in the blank test of field 19. For the smallest sized plat given, eight replications are necessary in order that a difference of 5% between two treatments can be termed significant.

BLANK TEST FIELD 21

In field 21, Kahuku, the experimental plan was of the Latin square type, having five beds of five plats each. The beds were 7½ feet center to center. Each plat was approximately 60 feet long and each third bed was selected and harvested as was done in Kunia field 19 and Pearl City field 82. The summary of fruit numbers and weights are found in Table 1. The Latin square design for our present purpose was an unfortunate one. The results obtained from this plan permitted only a small number of combinations. Hence only the standard deviation for a single plat one bed wide and 60 feet long was calculated. It is equal to 5.14%. The number of replications necessary for a 5% significant difference is equal to 8.5.

BLANK TEST FIELD 1, KUNIA

This experiment was another Latin square test having eight plats in each column and eight plats in each row. It was harvested in 1930. Each plat consisted of two beds 150 feet long. Beds were 6 feet center to center and consisted of three rows each. The entire experimental area occupied 2.85 acres. Fruit weights for the individual plats appear in Table 4.

Plats 1 to 8 constitute one block or column, plats 9 to 16 another, etc. Plats 8, 9, 24, 25, 40, 41, 56, and 57 are in the same row. Mean fruit weights are given in grams.

Nineteen combinations of various plat sizes were possible without eliminating plats for the determination of the standard deviations. Plat 8 was used as the starting point for all combinations. For instance, plats whose sizes were six beds wide and 150 feet long consisted of plats 8, 7, and 6; plats 5, 4, and 3; plats 9, 10, and 11; plats 12, 13, and 14; etc. In this combination, plats 1, 2, 15, 16, 18, 17, etc., were omitted from the calculations. The standard deviations of the various plat sizes are found in Table 5.

Figures in parentheses in Table 5 represent standard deviations resulting from the omission of several plats of the total area. As the plats increase in length from 150 feet to 1,200 feet, the rate of change

TABLE 4.—*Summary of fruit numbers and mean weights by plats in blank experiment field 1, Kunia.*

Plat No.	Number fruits	Fruit weights, grams	Plat No.	Number fruits	Fruit weights, grams
8 H	635	2,413	40 B	571	2,531
7 G	608	2,486	39 H	601	2,572
6 F	626	2,508	38 E	599	2,545
5 E	639	2,427	37 G	595	2,490
4 D	638	2,458	36 F	574	2,527
3 C	647	2,445	35 A	559	2,567
2 B	626	2,477	34 D	547	2,604
1 A	593	2,454	33 C	581	2,490
9 C	591	2,517	41 F	541	2,468
10 E	616	2,541	42 A	571	2,545
11 B	614	2,545	43 G	577	2,576
12 D	618	2,554	44 H	597	2,459
13 A	586	2,472	45 C	577	2,512
14 H	647	2,549	46 D	551	2,476
15 F	616	2,549	47 E	581	2,499
16 G	639	2,613	48 B	573	2,390
24 E	632	2,486	56 D	522	2,486
23 D	625	2,576	55 B	585	2,544
22 C	624	2,544	54 A	595	2,545
21 A	617	2,636	53 F	583	2,517
20 B	629	2,644	52 G	577	2,499
19 G	609	2,622	51 E	599	2,481
18 H	623	2,617	50 C	581	2,472
17 F	619	2,499	49 H	524	2,454
25 G	532	2,468	57 A	556	2,304
26 C	611	2,536	58 F	595	2,363
27 D	569	2,481	59 H	621	2,381
28 B	605	2,554	60 C	606	2,354
29 H	608	2,522	61 E	630	2,345
30 F	601	2,545	62 B	611	2,381
31 A	587	2,517	63 G	578	2,400
32 E	578	2,554	64 D	604	2,409
Total				38,170	
Mean					2,503

TABLE 5.—*Standard deviation of a single plat as percentage of the mean in field 1, Kunia.*

Number of beds	Bed lengths in feet							
	150	300	450	600	750	900	1,050	1,200
2	6.01	5.05	4.53	4.80		(2.01)*	(2.49)	2.30
4	5.14	4.46	4.17	4.43		(1.19)	(1.55)	1.79
6	(4.74)	(1.94)	(4.22)	(4.23)		(1.22)	(1.26)	(1.49)
8	4.76	4.19	(4.34)	4.42		(0.77)	(0.14)	0.14
10								
12	(4.52)	(4.01)	(5.02)	4.87				
14	(4.64)	(4.18)	(5.19)	5.07				
16	3.38	4.39	(5.28)	5.32				

*Figures in parentheses are standard deviation obtained from data of part of entire area.

in the standard deviation is rapid; as they increase in width, the change is relatively slower. The standard deviation of plats two beds wide and 150 feet long is somewhat higher than that found for Kunia field 19 and for Pearl City. The large sized plats have small standard deviations, many of which require less than one replication to measure significant differences. Anything less than one replication is absurd; so that for all cases it is understood that they should be equal to one, subject however, to the limitations discussed under blank test field 19.

The prominent features of a study of the results of the three contrasting areas are as follows:

1. Standard errors of single plats one bed wide and 60 to 76 feet long are about the same in the various localities tested and equal to approximately 5% of the mean. In field 21, Kahuku, the error is slightly larger, probably because the lengths of the plats are 15 feet shorter than those of the other fields.
2. Standard errors of a single plat in general decrease slowly as the size of the plats increases.
3. About eight replications are necessary to demonstrate that the yield of one treatment exceeds that of another by 5%.

FRUIT WEIGHT VARIATION STUDIES WITHIN A PLAT

Fruit weights harvested from plat 12, field 21, Kahuku, were taken for this study. Only fruit weights from the two inside rows were considered. The total number of fruits harvested was 100. A lot of 10 fruits was summed and its standard deviation evaluated. From this determination a standard deviation of the arithmetic mean or the standard error was calculated by the use of the familiar formula $\sigma m = \frac{\sigma x}{\sqrt{n}}$. Ten more fruits were added to the first lot and its standard deviation and standard error determined. In the same manner, standard deviations and standard errors for lots of 30, 40, 50, etc., fruit weights each were calculated. The results appear in Table 6.

TABLE 6.—*Standard errors for corresponding number of fruits, field 21, Kahuku, plat 12.*

Number of fruits	Sum	Standard deviations	Standard deviation in % of mean	Standard error in % of mean	Theoretical standard error in % of mean	
					$\frac{22.00}{\sqrt{n}}$	$\frac{25.55}{\sqrt{n}}$
10.....	16,120	354.7	22.00	6.95	6.95	8.08
20.....	36,540	440.3	24.10	5.39	4.92	5.71
30.....	54,400	418.6	23.09	4.22	4.02	4.66
40.....	73,320	428.2	23.36	3.69	3.48	4.04
50.....	93,020	405.4	21.79	3.17	3.11	3.61
60.....	111,440	469.9	25.30	3.27	2.84	3.30
70.....	128,100	468.0	25.57	3.06	2.63	3.05
80.....	146,740	450.0	24.53	2.74	2.46	2.86
90.....	164,980	455.6	24.85	2.62	2.32	2.69
100.....	183,920	469.9	25.55	2.56	2.20	2.56

The standard errors in percentage of the mean were plotted against the number of fruits per sample and appear as a broken line in Fig. 2. The standard errors decrease steadily as the number of fruits per sample increase.

On the basis of the first 10 fruits, the standard deviation of a single fruit is equal to 22.0% of the mean. If this represents the true standard deviation, we obtain a theoretical curve of the standard errors for any number of fruits in the sample. This appears as a full line in Fig. 2. The other full line is the locus of the curve of standard errors when the standard deviation of 25.55% for sample of 100 fruits was used.

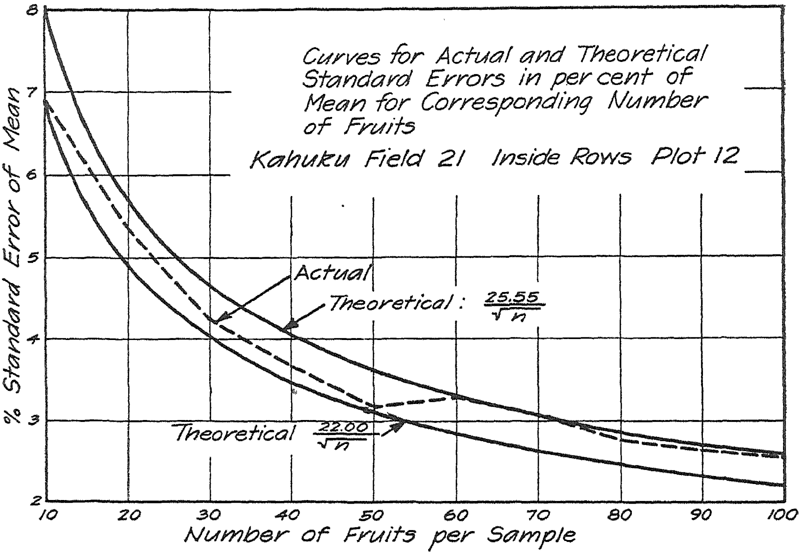

FIG. 2.—A graph of effect of numbers of fruits on actual and theoretical standard deviations.

The traces of both curves show fair agreement with the curve of actual determinations.

The standard deviations of all lots tend to have the same value. This value is approximately 24%. This is an indication that the average weight of a large number of fruits can be determined with a high degree of accuracy with a small sample of fruits, provided the distribution of the total population of fruit weights is normal or approximately so. Little would be gained by having a sample containing a very large number of fruits. A four-row bed, 75 feet long with plants set 18 inches apart contains 200 plants. With a standard deviation of 24% of the mean, it will be found that a sample of 200 fruits produces a standard error of 1.7% of the mean. Below are given the average number of fruits obtained from each unit plat and the standard errors of the mean, assuming a standard deviation of 24%.

Location	Average number of fruits per plat	Standard error in % of mean
Kunia field 19	171	1.8
Pearl City field 82	221	1.6
Kahuku field 21	171	1.8
Kunia field 1	596	1.0

The figures indicate that in our study an estimate of the true mean based on the fruits of single plats, none of which were less than 60 feet long, should lie within 2% of the estimated mean. This agrees with the results of Westover (4) who concluded that the increased accuracy obtained with single row plats of potatoes more than 40 feet long did not compensate for the added expense.

MAGNITUDE OF ERROR IN PAST EXPERIMENTS

We have two general methods for obtaining an estimate of error in experiments, first, externally through previous uniformity trials; and second, internally from the results of experiments themselves. Using the methods of Fisher and Wishart (2), the standard error for the single plat treatment and minimum level of significance have been calculated for a number of experiments. These results are shown in Table 7, together with the results from the blank tests already discussed in the earlier portion of this paper.

TABLE 7.—*A summary of calculated errors in field experiments.*

Experiment	Number of replications	Plat size, acres	Percentage of mean		
			Standard error		Minimum significance level
			Single plat	Treatment	
K. P. Co. field 5	3	0.3719	7.48	4.32	12.20
K. P. Co. exp. 3	4	0.1308	2.30	1.15	3.25
K. P. Co. exp. 9	5	0.0964	3.20	1.43	4.05
H. P. Co. field 18	3	Ca .1260	5.10	2.95	8.34
H. P. Co. field 85	3	Ca .1260	4.71	2.72	7.70
H. P. Co. L exp. 13	6	0.1440	6.95	2.84	8.03
H. P. Co. L exp. 14	6	0.1440	5.19	2.12	6.00
Libby exp. 98-C	4	Ca .0620	7.28	3.64	10.30
M. P. Co. exp. 14	6	0.0382	2.40	0.99	3.05
C. P. C. field 1	8 (64)*	0.0440	3.63	1.29	3.66
C. P. C. field 19	(24)	0.0111	5.05		
Pearl City field 82	(24)	0.0108	4.97		
C. P. C. field 21	5 (25)	0.0131	5.14		

*Numbers in parenthesis are the number of plats in each of these four blank tests.

A study of the data in Table 7 shows that no matter what the size of the plat, whether 0.37 acre or 0.01 acre, the error (standard error of a single plat) is about the same, namely, 5% of the mean. In two cases, field 1 and field 21, the error listed is slightly lower than it would be had these been calculated as the others. These two experiments were laid out as Latin squares. With such a plan, a portion of the total variance can be deducted as being accounted for by rows and columns. This leaves a smaller variance and the standard error is lower as a result.

It is reassuring to learn that pineapple fields throughout the Territory have, in general, about the same degree of uniformity, at least as expressed by fruit weights on a plat basis.

In the second to the last column of Table 7, standard errors for treatments have been calculated. Some of the older experiments have fairly high values mainly because of a small number of replications. The last column of this table is perhaps the most important, for it tells us, on the basis of odds of 20 to 1, what we can consider as the threshold of significant increase in each experiment. Thus while a very few experiments have been sufficiently accurate to label a 4% yield increase as reliable or significant, in most of the cases recorded increases or differences must exceed 8% to be reliable. Eight per cent of the yield is of great financial importance, and we must improve our experiments so as to detect smaller differences reliably. The more immediate methods appear to be a more uniform planting material, a more uniform fertilization, and greater plat replication. Of these, at the present time, the last is probably the most important, especially in that increased replications can easily be obtained.

PROPOSED PLANS FOR FIELD EXPERIMENTS

One of the first considerations in laying out an experiment is the question of border effect. No actual data on this factor appears to have been obtained with pineapples. The fact that border effect has been observed repeatedly, as well as the knowledge that plant roots in some cases extend from bed to bed, clearly indicates that border effect must be considered. This is especially true of fertilizer tests in which a plat receiving a nutrient which markedly increases its yield adjoins a plat poor in this plant food. Thus, while in tests of varieties and types of planting material, border effect probably can be ignored, in fertilizer tests provision should ordinarily be made for its cancellation.

Where records are to be obtained in a ratoon crop as well as plant crop, it becomes impracticable to harvest some rows within the bed only. In fertilizer tests, therefore, it seems desirable to set up plats three beds wide. The central bed is harvested in both plant crop and ratoons, while the two beds on the sides are not harvested as a part of the experiment.

The length of the plat need not be longer than 150 feet. This length is especially desirable on some plantations. In this case a small 2-foot path is left 150 feet from the end to mark the end of the plat, and fruit is carried out to the field road in both directions from this central path. With four lines or rows per bed, plats 75 feet long have been demonstrated to be amply large. Where other data are required and are to be checked during the various portions of the harvest season, more fruit per plat may be necessary. For the present, and for yield purposes especially, we recommend plats 75 feet long, or 150 feet long in cases where the plantation feels this is more desirable from the labor viewpoint. It is essential to remember, however, that the smaller the experimental area, the greater is the possibility for soil uniformity within this area.

The number of replications with these relatively small plats should be about six to eight. With six replications we can expect to demonstrate that a yield increase of 6% is significant, while eight replications should prove a 5% increase as significant. It appears impracticable to go beyond this point at present.

With four to six treatments the Latin square design is well suited. A few such experiments have been conducted with pineapples, but most plantations object to this design from the practical consideration of installation, field operations, and harvesting. Both the randomized block and Latin square systems are well illustrated by Wishart and Fisher (2).

PLAT DISTRIBUTION

The primary requisite which most experimenters lay down is that plat distribution shall be random with some restrictions. The randomized block method is the preferred type where there are more than six treatments. Each treatment is present once, randomly as to position, in a block, and there are as many blocks as there are replications.

SUMMARY

In order to obtain evidence on yield uniformity in small adjacent plats, a statistical analysis of fruit weights of blank tests conducted in three contrasting regions was investigated. Locations of these areas were at fields 1 and 19, Kunia; field 82, Pearl City; and field 21, Kahuku. All these areas are located on the island of Oahu.

The object was to find the amount of soil variation which may be expected from the use of different plat sizes. The standard errors in percentage of the mean in all cases decreased when the size of plats increased.

With approximately eight replications, plats one bed wide and 75 feet long were large enough to measure a 5% yield increase as significant. From certain considerations it is recommended that plats three beds wide and 75 to 150 feet long be used in which only the central bed is harvested.

A measure of field variation was studied from a consideration of a sample of 100 fruit weights obtained from two inside rows of a plat.

Experimental errors of many past experiments are presented. It was learned that the fields in general throughout the Territory of Hawaii have about the same degree of uniformity.

Plat distribution in randomized blocks is discussed, and reference is made to its distribution in a Latin square layout. Both types help to increase the accuracy of the experiment.

LITERATURE CITED

1. DEMANDT, E. Die Resultaten der Blanco Proeven met 2878 POJ van Oogstjaar 1931. Archief vor Suikerindustrie in Nederland Indie—Deel III. Med. van het Proefstation voor Java Suikerindustrie, Jahrgang 1932, No. 14. 1932.

2. FISHER, R. A., and WISHART, J. The arrangement of field experiments and the statistical reduction of the results. Imperial Bur. Soil Sci., Tech. Comm. No. 10. 1930.
3. MERCER, W. B., and HALL, A. D. The experimental error of field trials. Jour. Agr. Sci., 4 : 107–132. 1911.
4. WESTOVER, K. C. Influence of plot size and replication on experimental error in field trials with potatoes. West Va. Agr. Exp. Sta. Bul. 189. 1924.

THE SALT CONTENT OF SOME SOILS NEAR THE SALT PLAIN IN ALFALFA COUNTY, OKLAHOMA, IN RELATION TO CROP PRODUCTION[1]

H. F. MURPHY[2]

It is the purpose of this paper to present some data showing the salt content which wheat land in the Great Plains may have and yet produce a profitable yield. A few other crops are also included, but for the most part data on these are rather limited. Data on the soluble and replaceable sodium and calcium for these solonchak soils, as well as for some solonetz soils, are presented.

DESCRIPTION OF THE AREA AND SOILS EXAMINED

The Alfalfa County salt plain lies south of the Salt Fork of the Arkansas River, about 4 miles east of Cherokee, Oklahoma. It covers an elliptical area of about 60 square miles. The plain is practically level, and is absolutely devoid of vegetation except for a few grassy mounds near the edge. The farm land surrounding the plain is slightly higher than the plain and is nearly level. It is used primarily for wheat production, although some other crops, such as grain sorghums, corn, oats, sudan grass, barley, and alfalfa, are grown to a limited extent. Native grass, largely *Andropogon scoparius* and *A. furcatus*, is found surrounding and even growing on the grassy hammocks occurring within the borders of the salt bed. There is, however, a considerable acreage of land lying southwest and northwest of the plains proper in which scattered areas occur where the salt content is such as to make them unproductive. Such areas are commonly found in the wheat fields, and are so numerous and of sufficient size as to reduce greatly the yield of wheat. The boundary between excellent wheat and absolutely barren soil is usually sharp and quite distinct, though in some instances narrow borders of inferior crops occur. Twelve sandy loams, 16 loams, 16 silt loams, 4 silty clay loams, 43 sandy clay loams, and 18 clay soils were studied.

METHOD OF PROCEDURE

Samples of soil were collected in the field by means of a soil auger or with soil tubes, and placed in sampling sacks. They were taken to the laboratory and allowed to air dry. The surface 6 inches are

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[2] Associate Professor of Soils. The author is indebted to H. A. Daniel for some of the analyses reported here.

taken as the basis of study unless otherwise described. The equivalent of 50 grams of oven-dry soil was placed in a 500-cc Erlenmeyer flask with 250 cc of distilled water and shaken intermittently every 5 minutes for 30 minutes; after which it was filtered using suction and aliquots of the filtrate were used for soluble salt studies. The pH was determined with the quinhydrone electrode using 1 part of soil to 2 parts of distilled water.

For the determination of replaceable (including soluble) calcium and sodium, 1 part of air-dried soil to 2 parts of neutral normal ammonium acetate was heated in a water bath for 2 hours at 70°C and then thrown on a filter and leached with more of the acetate solution until the leachate showed no calcium present. Aliquots were taken and the calcium and sodium present in the leachate were determined. The calcium was precipitated in the usual manner and titrated with standard $KMnO_4$, while the sodium was determined by the Barber and Kolthoff[3] method as described by Salgado[4] for ammonium acetate leachates.

RESULTS, COMMENTS, AND DISCUSSION

The general results are found in Tables 2, 3, and 4. The pH of the various soils are not given in the tables; however, the range for the soils not supporting any vegetation was pH 6.92 to 8.10. This was not unlike soils supporting vegetation. Of the locations examined, including both soils supporting vegetation and barren soils, there were 21 having a pH between 6 and 7, 73 with a pH range of 7 to 8, and 18 having a pH range of 8 to 8.6. Two soils had a pH below 6 and were growing wheat. Only three barren soils had a pH of 8 or above. Soils supporting the best growth of wheat ranged from pH 5.62 to 7.91. Only two soils in this group had a pH below 7.00.

The pH of the soils was usually about one-half a unit higher after the 1 : 5 water extration and air drying. Some typical results are shown in Table 1. Data are not included in the tables relative to the sulfate content of these soils, but sulfates made up a very large part of the remainder of the salts other than chlorides. No carbonates were detected in the filtrate, although some of the soils showed an effervescence when treated with dilute HCl. The data on pH indicate that the reaction of the soil is not adverse to crop production and that it is the soluble salt content and low Ca-Na ratio which is causing the soil to be barren. Some of the best yields of wheat are being produced on soils having an alkaline reaction as high as that of the barren soil.

Since most of these samples were collected either during the month of May or in October, it was possible to judge fairly accurately as to the probable yield of the various crops. Inferior vegetation so far as wheat is concerned applies to estimated yields of 5 bushels or less, while good vegetation refers to yields of over 10 bushels per

[3] BARBER, H. H., and KOLTHOFF, I. M. A specific reagent for the rapid determination of sodium. Jour. Amer. Chem. Soc., 50 : 1625–1631. 1928.

[4] SALGADO, M. L. M. A study of the exchangeable bases in some East Anglian soils derived from the Jurassic and Cretaceous sediments, with special reference to their marine origin. Jour. Agr. Sci., 23 : 18–30. 1933.

TABLE 1.—*The pH of the soils before and after extracting with distilled water.*

Vegetative covering	pH of soil before extraction	pH of soil after extraction	Soluble salt %
Barren	6.87	7.20	1.544
Good vegetation (wheat)	7.15	8.00	0.090
Barren	7.68	8.19	2.622
Good vegetation (wheat)	7.46	7.90	0.218
Barren	7.58	8.07	3.310
Good vegetation (wheat)	7.72	8.35	0.398
Good vegetation (sweet clover)	7.97	8.60	0.334
Barren	7.83	8.46	1.138
Good vegetation (cowpeas)	7.83	8.35	0.170
Barren	7.84	8.36	0.914
Good vegetation (alfalfa)	7.48	7.97	0.361
Barren	7.97	8.52	3.134
Good vegetation (sweet clover)	8.10	8.59	0.314
Barren	7.49	8.14	1.186
Good vegetation (wheat)	8.50	8.52	0.068

acre; usually this amounted to 15 to 20 bushels of wheat per acre. Inferior vegetation with respect to corn, kafir, and cane infers that only forage was produced and in most cases the yield of this was small. As inferior vegetation is so defined the total salt content of all soils supporting such vegetation for all crops concerned was 0.518%, and for the wheat plant alone it amounted to 0.559%. Soils designated as producing good wheat averaged 0.224% soluble salts. If what is considered good wheat is divided into groups with estimated yields of 10 bushels and 15 bushels or more per acre, the soils producing 10-bushel wheat averaged 0.336%, while those producing the higher yield averaged 0.193%. As indicated by the data in Table 2, if the surface soils contain more than 0.6% soluble salts, wheat cannot be expected to make more than a very inferior yield, usually not over 5 bushels per acre. Approximately 0.4 to 0.5% is the upper limit for 10-bushel wheat; and if the salt content is less than 0.4% and if other factors are favorable, better than 10-bushel wheat can probably be produced on these soils. The highest amount of total soluble salts present in the surface soil producing over 15 bushel wheat was 0.398%.

These figures would be modified considerably by a dry condition of the soil at planting time. For the most part the wheat data are on soils where fall precipitation was favorable for germination and development of the young plant. Where soil moisture was adverse to good growth in the fall, the young wheat plants died on a soil analyzing 0.532% soluble salts, but grew very nicely on nearby soil analyzing 0.194%. Data on the corn plant also show the influence of climate. Corn was found growing nicely in May, 1928, where the soluble salt content of the surface soil was 0.624%, but it failed in soil analyzing 1.015%. A few small stalks producing no grain grew during the 1928 season on soil where the surface contained 0.866%. The following year only a few small stalks grew on soil analyzing 0.443% soluble salts in October. The summer rainfall was much better distributed during 1928 than during 1929. The total annual rainfall in the area is 25 to 30 inches.

TABLE 2.—*Some typical results on the salt content of soils supporting various degrees of vegetation.*

Crop	Percentage of soluble salts present			
	No vegetation		Inferior vegetation	Good vegetation
	Soluble salts	NaCl		
Wheat	1.544	0.556	——	0.090
Wheat	1.152	0.269	——	0.140
Wheat	2.622	0.834	0.518	0.218
Wheat	3.310	1.141	——	0.424
Wheat	——	——	——	0.398
Wheat*	0.532	——	——	0.194
Wheat	1.344	0.278	0.340	0.266
Wheat	1.222	0.439	0.584	0.346
Wheat	2.792	1.009	0.382	——
Wheat	1.526	0.117	0.648	0.318
Wheat	——	——	0.636	——
Wheat	1.238	0.117	——	0.232
Wheat	3.676	1.272	0.616	0.220
Wheat	2.104	0.117	0.892	——
Wheat	1.472	0.263	0.350	0.140
Wheat	1.186	0.380	——	0.068
Wheat	3.874	1.828	0.624	0.218
Corn	2.116	0.117	0.624†	——
Corn	1.015	0.293	0.866	0.198
Corn	1.114	——	0.443‡	0.213
Corn	——	——	——	0.185
Native grass	7.298	3.071	——	0.262
Russian thistle	——	——	——	1.297
Foxtail and sandburs	——	——	——	0.866
Oats	2.412	0.527	——	0.064
Sudan	——	——	0.508	——
Sweet clover	2.938	1.082	——	0.314
Cowpeas	0.894	——	——	0.170
Cowpeas	1.138§	0.234	——	——
Alfalfa	2.287	0.632	——	0.732
Alfalfa	0.914	——	0.369	0.361
Cane (sowed)	——	——	0.296‡	0.226
Kafir	2.987	0.948	——	0.557
Kafir	1.373	0.538	——	0.185
Kafir	1.086	0.302	——	0.592
Kafir	1.809	——	0.300‡	0.200
Kafir	1.033	——	0.335‡	0.232
Kafir	——	——	——	0.135

*Young wheat starting growth in a soil considerably below optimum moisture content.

†Nice vegetative growth in May, but yielded little grain for the season.

‡Forage only.

§Cowpea seed rotted in soil where the soluble salt content was 0.334%.

TABLE 3.—*The soluble salt content of several soil profiles.*

Profile No.	Vegetation	Depth, inches	Soluble salts %	NaCl %*
1	Wheat failure	0–4 6–12	7.298 0.970	3.071 0.205
2	Wheat failure	0–6 24–36	2.246 1.834	1.170 0.219
3	Sweet clover failure	0–6 24–36	3.134 1.960	0.424 0.161
4	Wheat failure	0–6 24–36	2.938 1.840	1.082 0.161
5	Wheat failure	0–4 24–36	1.526 2.090	0.117 0.044
6	Wheat failure	0–4 24–36	1.938 1.390	0.395 0.088
7	Wheat failure	0–4 12–24 24–36	3.874 1.314 1.372	1.828 0.424 0.410
8	Wheat failure	0–4 12–24 24–36	2.622 1.430 1.500	0.834 0.132 0.088
9	Good wheat	0–4 12–24 24–36	0.218 0.248 2.752	0.015 0.073 0.102
10	Good wheat	0–4 24–36	0.232 0.346	0.029 0.102
11	Fair wheat	0–4 24–36	0.318 0.286	0.029 0.029
12	Poor wheat	0–4 24–36	0.648 0.406	0.029 0.015
13	Good sweet clover	0–6 24–36	0.314 1.856	0.073 0.059
14	Good wheat	0–6 24–36	0.140 2.256	0.015 0.102
15	Alfalfa failure	0–4 12–18 24–36	2.286 2.183 2.312	0.632 0.316 0.374
16	Good alfalfa	0–4 12–18 24–36	0.732 1.675 2.369	0.105 0.187 0.164

*All chlorides were calculated as NaCl.

Data on the salt content of soil which would prevent any growth when moisture conditions were favorable during the early part of the season and fairly well distributed during the growing season, could

TABLE 4.—*Showing the calcium and sodium content and the calcium-sodium ratio of the leachate from soils leached with neutral normal ammonium acetate.*

Location	No vegetation			Good wheat		
	M. E. of Ca per 100 grams	M. E. of Na per 100 grams*	CaNa ratio	M. E. of Ca per 100 grams	M. E. of Na per 100 grams	CaNa ratio
1.......	3.10	11.74	0.26	2.75	0.46	5.98
2.......	4.40	3.97	1.11	3.10	0.15	20.68
3.......	3.25	13.60	0.24	4.05	0.55	7.36
5†......	5.25	2.69	1.95	3.55	0.40	8.87
6.......	6.32	6.93	0.91	4.40	0.07	62.80
7.......	6.20	4.31	1.44	3.25	0.06	54.20
9.......	1.70	3.11	0.55	2.60	0.05	52.00
10.......	7.95	7.17	1.11	3.15	0.81	3.89
13.......	5.55	4.85	1.13	3.00	0.54	5.55
14.......	6.90	5.34	1.29	4.30	0.17	25.29
17‡......	4.10	6.85	0.60	3.45	0.97	3.56
19§......	2.70	4.82	0.56	7.30	0.13	56.15
24‖......	2.70	4.82	0.56	7.30	0.13	56.15
31**.....	3.40	10.75	0.32	9.50	0.92	10.33

*Water-soluble sodium made up 82.84% of that present in the acetate leachate in 12 typical barren soils. The range was 71.32 to 93.17%.

†Young wheat in dry soil. ‡Cowpeas. §Alfalfa. ‖Corn. **Kafir.

TABLE 5.—*Data on corresponding productive and non-productive solonetz soils on the Oklahoma Experiment Station farm.*

Type of vegetation	Depth, inches	pH	Soluble salts %	Soils leached with ammonium acetate		
				M. E. of Na per 100 grams	M. E. of Ca per 100 grams	CaNa ratio
Good darso...	0–4	5.66	0.038	0.13	1.30	10.00
	12–18	5.82	0.031	0.07	2.15	30.71
Very inferior darso*.....	0–4	7.00	0.137	4.38	1.25	0.29
	12–18	8.14	0.406	14.75	3.85	0.26
Good darso...	0–4	6.66	0.038	0.04	1.65	41.25
	12–18	7.68	0.029	0.10	2.75	27.50
No vegetative growth.....	0–4	8.56	0.085	2.71	1.20	0.44
	12–18	9.00	0.323	9.12	2.70	0.30
Good darso...	0–4	5.83	0.071	0.08	1.45	18.13
Very inferior darso......	0–4	7.46	0.076	2.33	0.75	0.32
Good darso...	0–4	6.03	0.024	0.12	1.20	10.00
	12–18	6.01	0.050	0.12	2.15	17.92
Very inferior darso......	0–4	8.29	0.094	3.04	0.75	0.25
Good cowpeas.	0–4	5.75	0.033	0.14	1.40	10.00
No vegetative growth.....	0–4	7.58	0.066	2.09	1.25	0.60

*Very inferior growth indicates no heads and only meager stalk growth.

inches apart. Hairy vetch was planted with wheat in the autumn, these rows also being 8 inches apart. The following year a cereal was grown without an auxiliary crop. Both the auxiliary crops and the legume grain crops differ from the hay crops in one important respect, namely, that they were grown to maturity, while the hay crops were cut before full bloom.

Soil in the frames consisted of a mixture of 60% Dunkirk silty clay loam and 40% fairly clean sand. The soil and sand were carefully mixed in quantity sufficient to furnish one wheelbarrow load for each frame. After this had been placed in each of the 48 frames, similar quantities of soil and sand were mixed and distributed in the same manner. This procedure was continued until the frames were filled. The average nitrogen content of the soil of the 48 frames was 0.0842%. In order that nitrogen should be, as far as possible, the limiting factor, the soil was liberally supplied with lime, phosphorus, and potassium. The plants were watered with rainwater from a cistern in time of drought. No nitrogen was applied in fertilizer or other manure at any time during the experiment.

Soil samples for determinations of total nitrogen were taken from each frame at the beginning of the experiment in 1921 and again in 1931. Borings were made to a depth of 8 inches, as that was nearly as deep as the mixed soil placed in the frames. Since there was no erosion by water and practically none by wind, some of the most obvious sources of error in experiments of this kind were absent.

The entire crop, at each cutting, was dried in an oven, sampled, ground in a Wiley mill and total nitrogen determined. On the basis of lysimeter experiments under somewhat similar conditions it was assumed that the nitrogen carried down by rain and snow added to the nitrogen applied in rainwater from the cistern about equaled that removed in the drainage water. The tables of this report are compiled from data obtained in this way.

Table 1 shows the quantity of nitrogen contained in all the crops harvested from replicate frames during the period of the experiment, also the gain or loss of soil nitrogen which took place between the dates on which soil samples were taken in 1921 and 1931. From these data are calculated the total and average annual accretion of nitrogen for each combination of legume and cereal during the 10 years. The nitrogen accretion is found by adding to the quantity of nitrogen in the crops the gain of nitrogen by the soil, or by subtracting the loss of nitrogen in the soil, if such occurred. It is assumed that there was no material escape of soil nitrogen in gaseous form during the period covered by the experiment. This assumption is based on lysimeter experiments under rather similar conditions in which loss of gaseous nitrogen was estimated by measurement of income and outgo of all other forms of nitrogen. Quantities of nitrogen are expressed in terms of pounds per acre in crops and pounds per 2,500,000 pounds of soil.

A comparison of the quantities of nitrogen in crops as stated in Table 1 shows that alfalfa, together with cereals alternated with it, contained more nitrogen than did any other combination of legume and cereal. However, alfalfa grown continuously contained the

TABLE 1.—*Nitrogen accretion during experimental period calculated to pounds of nitrogen per 2,500,000 pounds of soil.*

Frame numbers	Cropping system	Nitrogen in all crops, lbs. per acre	Nitrogen in soil, loss or gain in lbs. per acre	Apparent fixation of nitrogen during experiment	
				Total, lbs. per acre	Average annual lbs. per acre
49, 61N, 49, 61S.....	Red clover alternating with barley or rye	868	532	1,463	146
50, 62N, 50, 62S.....	Alsike clover alternating with barley or rye	830	595	1,362	136
51, 63N, 51, 63S.....	Alfalfa alternating with barley or rye	1,804	607	2,411	241
52, 64N, 52, 64S.....	Sweet clover alternating with barley or rye	1,214	420	1,634	163
53, 65N, 53, 65S.....	Vetch & Wheat alternating with barley or rye	549	97	646	65
54, 66N, 54, 66S.....	Red & alsk. clo. alternating with barley or rye	1,054	577	1,631	163
55, 67N, 55, 67S.....	Sweet clo. & vetch alternating with barley or rye	1,155	410	1,565	156
56, 68N, 56, 68S.....	Soy beans alternating with barley or rye	1,058	—42	1,016	102
57, 69N, 57, 69S.....	Peas & oats alternating with barley or rye	493	—32	461	46
58, 70N, 58, 70S.....	Field beans alternating with barley or rye	672	—100	572	57
59, 71N, 59, 71S.....	No legume, barley, rye, or oats each year	223	—52	171	17
60, 72N, 60, 72S.....	Alfalfa continuously	2,179	505	2,684	268

greatest quantity of nitrogen. During the first 3 or 4 years of the experiment sweet clover produced crops with nearly as much nitrogen as did alfalfa, but later the yields of sweet clover were smaller. Whether this decrease in yields of sweet clover was due to "soil sickness" or to winter killing or to some other pathogenic condition of the sweet clover, was not ascertained. Resort was had to annual sweet clover, but yields never again reached the figures of the first few years. So far as sweet clover is concerned the experiment was not satisfactory.

Red clover and alsike clover with alternated cereals showed little difference in nitrogen accretion, but the mixture of these two clovers was much more effective than was either one separately. Of the legume grain and auxiliary crops soy beans were outstanding in their ability to fix nitrogen. The other legumes in these two classes, which comprised vetch, field peas, and field beans, were much less effective. However, any legume was better than none as shown by the small accumulation of nitrogen by the cereals grown alone.

Glancing at the column showing the figures for gain or loss of soil nitrogen during the experiment, it will be seen that it was not always the case that a legume producing a large amount of nitrogen in the crops left a proportional quantity of nitrogen in the soil. Although there was some tendency in this direction, there were outstanding exceptions. For instance, the mixture of red and alsike clovers contained 1,054 pounds of nitrogen per acre in all the crops and there was a gain of 577 pounds of nitrogen in 2,500,000 pounds of soil, while soybeans, although containing 1,058 pounds of nitrogen in the crops, was accompanied by a loss of 42 pounds of nitrogen in the soil.

The legumes grown for hay were notably more effective than were the other legumes in causing a gain of soil nitrogen. Of the other legumes, all save vetch occasioned a loss of nitrogen. In the soil on which field beans were grown there was a greater loss of nitrogen than occurred in the soil on which no legume was grown.

Increases in the quantities of nitrogen in the soil of some of the frames were very large. However, the conditions were favorable for such gains, especially so since the nitrogen content of the soil was unusually low at the beginning of the experiment. It is perhaps more striking that there should be losses of soil nitrogen where legumes of any kind were grown. This appears to be an illustration of the influence of legumes in making soil nitrogen readily available.

Referring to the column showing the apparent fixation of nitrogen there are seen to be large differences between legumes of various kinds. Alfalfa was most active in this respect, followed somewhat tardily by sweet clover and also by the mixture of red and alsike clovers. This mixture proved to be superior by a significant margin to either of its constituents grown separately. In respect to apparent fixation, all the legumes demonstrated considerable activity, as may be seen by comparing the frames in which any of them were grown with the frames in which cereals were grown without any legumes. Even non-symbiotic fixation averages about 17 pounds annually in roughly 1 acre of land.

RELATION OF THE INITIAL TO THE RESIDUAL NITROGEN CONTENT OF THE SOIL AND TO NITROGEN IN CROPS

The relation of the nitrogen content of the soil at the beginning of the experiment to nitrogen accumulation by crops, and to gain or loss of soil nitrogen, may be seen by a comparison of these phenomena on the soil described above with a Dunkirk silty clay loam used in another experiment and not mixed with sand. Fortunately, some of the cropping systems followed in the two experiments had sufficient in common to admit of comparisons between these two soils in respect to gains and losses of nitrogen. It must be borne in mind that, in addition to the difference in nitrogen content, there was also a difference in texture between these two soils due to the addition of sand in one experiment, as has already been explained. Whether the texture was a factor in the results obtained is problematical. The possibility of texture being a factor in the results will be ignored in the discussion which follows.

The Dunkirk silty clay loam in its undiluted form contained 0.12% total nitrogen at the beginning of the experiment in which it was used. It will be remembered that the soil in the experiment previously described contained 0.084% nitrogen, being slightly more than two-thirds as much as was contained in the undiluted soil. In Table 2 are given some data comparing the results obtained on the two soils.

TABLE 2.—*Nitrogen in crops and loss or gain of nitrogen in soil, annual average.*

Frame numbers	Relative content of nitrogen in soil	Cropping system	Loss or gain of nitrogen in 2,500,000 lbs. soil, lbs.	Nitrogen in crops, lbs. per acre
22, 46..........	High	No legume, cereals only	—9	42
59, 71N, 59, 71S..	Low	No legume, cereals only	—5	22
4, 28...........	High	Alfalfa continuously	19	275
60, 72N, 60, 72S..	Low	Alfalfa continuously	50	218
23, 47..........	High	Red. clover 4 times in 10 years...........	19	123
49, 61N, 49, 61S..	Low	Red clover 5 times in 10 years	59	87
71, 31..........	High	Alfalfa 6 times in 10 years	7	226
8, 32...........	High	Alfalfa 4 times in 10 years	4	170
51, 63N, 51, 63S..	Low	Alfalfa 5 times in 10 years	61	180

In respect to soil nitrogen it is apparent that the gains of nitrogen are greater and the losses of nitrogen less in the low-nitrogen than in the high-nitrogen soil. This holds for all the cropping systems contained in Table 2. These are as follows: (1) When no legume was grown, (2) when alfalfa was grown continuously without any cereal, and (3) when red clover and also alfalfa were grown in crop rotations.

Under the cropping systems mentioned above there was more nitrogen in the crops grown on the soil of high-nitrogen content than on the low-nitrogen soil. The greater gains of nitrogen in the low-nitrogen soil are probably to be accounted for by the smaller quantities of nitrogen removed in the crops.

SUMMARY

Various legumes, alone and in combination with other crops, were grown for 10 years on a soil with an initial nitrogen content of 0.0842%. Nitrogen was determined in the soil at the beginning and at the end of the experiment, and in all the crops grown during the period.

Alfalfa and the cereals alternated with it contained more nitrogen than did any other combination of legumes and cereals. Red clover and alsike clover were approximately equal in nitrogen contained in the crops, but the mixture of the two clovers was superior to either one separately. Of the legume grain crops, soybeans was the most effective. The rotation without legumes contained the smallest quantity of nitrogen.

The gains in soil nitrogen in some cases were large. Generally the larger gains in soil nitrogen were associated with large amounts of nitrogen in crops. Of the legumes, those grown for hay were the most effective in increasing soil nitrogen. Field beans caused the greatest reduction of soil nitrogen of any crop grown.

The greatest apparent fixation of nitrogen was shown by alfalfa followed by sweet clover and a mixture of red and alsike clovers. The mixture of red and alsike clovers was superior to either grown alone. All rotations which included legumes showed significant apparent fixation. Non-symbiotic fixation amounted to 17 pounds of nitrogen to the acre annually.

Comparison of the data obtained with those secured on a soil with a higher initial nitrogen content showed that the gains of soil nitrogen were greater and the losses less in the low-nitrogen soil. These differences are accounted for by the larger quantities of nitrogen removed by the crops from the high nitrogen soil.

THE TRANSITION OF CITRATE-SOLUBLE PHOSPHATE INTO THE CITRATE-INSOLUBLE FORM IN MIXTURES WITH LIMESTONE AND WITH DOLOMITE[1]

W. H. MacIntire and W. M. Shaw[2]

Along with the increase in the use of ammonium salts in mixed fertilizers has come a wider recognition of the need for supplements of calcium and magnesium. This need has been discussed by Parker (5)[3] and the necessity for a dependable method of analysis to determine the amount and form of calcium and magnesium supplements in fertilizers has been pointed out by the senior author (1). Recently a method was proposed by Pierre (6) for the determination of the potential acidity of a mixed fertilizer. The Association of Official Agricultural Chemists is now studying methods for the determination of "available magnesium".

The compatibility of ammoniates with limestone and dolomite and the differential activities of the two types of limestone toward the phosphatic components of standard superphosphate were reported in three contributions from the Tennessee Experiment Station (2, 3, 4). In one study admixtures of the two types of limestone were made under optimal conditions and kept for periods of time to be expected in home mixing and also in commercial practice, where the supplemented cured product is subject to evaluation by the official control chemist. In the other case, aqueous solution-suspensions of the mono-, or water-soluble, calcium phosphate and dolomite were used to determine the speed and extent of reactions and composition of the end-products. In both cases, periodic determinations of evolved CO_2 were utilized to record the speed and the extent of the reactions.

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[1] Contribution from the Department of Chemistry, University of Tennessee Agricultural Experiment Station, Knoxville, Tenn. Received for publication February 6, 1934.

[2] Head of Department and Associate Soil Chemist, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 661.

It was shown that the addition of high-calcic limestone to superphosphate may result in a considerable decrease in the commercial evaluation of the supplemented product, whereas no such effect could be found for dolomite supplements. It appeared that the use of dolomite *under ordinary conditions* results in the formation of di-phosphates only. The characteristic drying-out effect and the balance between loss of CO_2 and moisture transformed from the hygroscopic state to water of combination, gave dolomite-superphosphate mixtures of near-constant weight and of a dryness that effectually stopped reactivity beyond the di-phosphate stage.

The present supplemental study was planned to show to what extent this final change may be anticipated when superphosphates supplemented with limestone, or with dolomite, are stored for an extended period in humid atmospheres. It was intended to impose conditions that would accentuate the transitions to the ultimate that could be expected in either home mixing or commercial practice.

EXPERIMENTAL

Fifty-six identical mixtures of a "C. P." di-calcium phosphate and 100-mesh limestone and 56 100-mesh dolomite mixtures were made in individual porcelain dishes of 30-cc capacity. Each charge of 1.07 grams of the "citrate-soluble" di-calcium phosphate was equivalent in P_2O_5 content to 1 gram of mono-calcium, or water-soluble, phosphate. A 0.875-gram constant was used for the additions of limestone and dolomite, this charge being the same as that used in the previous mono-calcium phosphate studies (3, 4) and 10% in excess of the amount required to transform the water-soluble equivalent to the di- form and on to the tri- form. Hence, in the present study the limestone and dolomite supplements were more than twice the amount required to convert the constant experimental charges of di-phosphate to the tri- combination. The high-calcic limestone contained 98% $CaCO_3$ and 1% $MgCO_3$. The dolomite contained 52½% $CaCO_3$ and 37½% magnesium carbonate. The di-phosphate used was J. T. Baker's, and on analysis showed 40.54% CaO and 52.41% P_2O_5 against respective theoretical occurrences of 32.56% and 41.30% for the fully hydrated product $CaHPO_4.2H_2O$. Since the $CaO:P_2O_5$ ratio found was 1.29 as compared with a theoretical ratio of 1:1.27, it is evident that the diphosphate used was not completely hydrated.

Each di-phosphate-limestone and di-phosphate-dolomite charge was first mixed thoroughly in the dry by means of an individual stirring rod, each mixture and stirring rod remaining in the original dish throughout the experiment. Immediately after the initial dry mixing, December 16, 1932, distilled water was added to each mixture until the stirred mass became a slurry, or paste. The mixtures were wetted each week thereafter throughout the first 10 months of the 12-month experimental period, with no further additions of water during the last 2 months. The contents were constantly exposed to a humified atmosphere in a room segregated from laboratory fumes. At the end of the first week, four units of the limestone and four of the dolomite mixtures were transferred to 300-cc Erlenmeyer flasks and residual carbonates computed from gravimetric determinations of evolved CO_2. Each full charge with its admixture of either limestone or dolomite was used as an analytical charge for the carbonate determinations. The periodic determinations of residual carbonates, CO_2 losses, and computed phosphate transitions are given in Table 1.

TABLE 1.—*The extent of tri-phosphate* formations in moistened mixtures of di-calcium phosphate† and 100-mesh limestone and dolomite during a year's period, as measured by carbonate disintegrations.*

Contact period		Grams residual carbonate CO_2 from admixtures of limestone and dolomite‡					CO_2 lost	
Month	Extent	1	2	3	4	Ave.	Grams	As % tri-phosphate formed§
		Limestone Mixtures						
Dec....	1 week	.3275	.3265	.3325	.3300	.3291	.0524	30.0
Jan....	1 month	.3265	.3275	.3245	——	.3262	.0553	31.7
Feb....	2 months	.3200	.3300	.3305	.3185	.3248	.0567	31.9
Mar....	3 months	.3230	.3130	.3275	——	.3212	.0603	34.6
Apr....	4 months	.3220	.3240	.3210	——	.3223	.0592	33.9
June...	6 months	.3000	.2960	.3110	.3110	.3045	.0770	44.1
Aug....	8 months	.2780	.2830	.2800	——	.2803	.1012	58.0
Sept...	9 months	.2690	.2830	.2760	——	.2760	.1055	60.5
Dec....	1 year	.2780	.2810	.2790	——	.2793	.1022	58.6
		Dolomite Mixtures						
Dec....	1 week	.3950	.3920	.3915	.3970	.3939	.0036	2.1
Jan....	1 month	.3940	.3940	.3955	.3970	.3951	.0024	1.4
Feb....	2 months	.3960	.3920	.3875	.3930	.3921	.0054	3.1
Mar....	3 months	.3950	.3980	.3920	.3975	.3956	.0019	1.1
Apr....	4 months	.3940	.3920	.3880	——	.3913	.0062	3.6
June...	6 months	.3890	.3890	.3890	.3830	.3875	.0100	5.7
July...	7 months	.3830	.3710	.3820	——	.3787	.0202	11.6
Aug....	8 months	.3780	.3470	.3630	——	.3627	.0342	19.6
Sept...	9 months	.3830	.3460	——	——	.3645	.0320	18.3
Dec...	1 year	.3440	.3640	.3440	——	.3507	.0468	26.8

*Citrate-insoluble. †Citrate-soluble.
‡0.3815 gram initial charge of limestone; 0.3975 gram initial charge of dolomite.
§In relation to theoretical.

From the data of high-calcic limestone mixtures, it is evident that the 30% transition of di-calcium to tri-calcium phosphate found after the first week increased very slowly during the next 4 months. During the succeeding warmer months, and until September, there was a further increase from the value of one-third of theory until the value of approximately 60% was reached and this value was maintained until the end of the year of exposure. Until April, the transitions shown for dolomite mixtures were less than 1/10 of those found for the limestone mixtures. During the succeeding warm months, the dolomite mixtures registered an accelerated reaction, but the ultimate transitions found for the dolomite were less than ½ those shown for the limestone mixtures. (See Fig. 1.)

When the final carbonate analyses were made, the limestone mixtures were well caked, whereas the dolomite mixtures were in a powdery and readily disintegrated condition. A complete mixture of each type was analyzed for "citrate-insoluble" P_2O_5 by the A. O. A. C. method at the end of approximately 13½ months of contact. After correction for the "citrate-insoluble" value found for the full charge of di-calcium phosphate alone, the citrate-insoluble P_2O_5-content of the limestone mixture was found to be 9.04% of the P_2O_5 content of the original phosphate charge, whereas the "citrate insoluble" value found for the dolomite mixtures was only 0.44%. The corresponding phosphate transition values, computed from the CO_2 losses given in Table 1, would be 19.5% (1/3 of 58.6) and 8.9% (1/3 of 26.8), respectively.

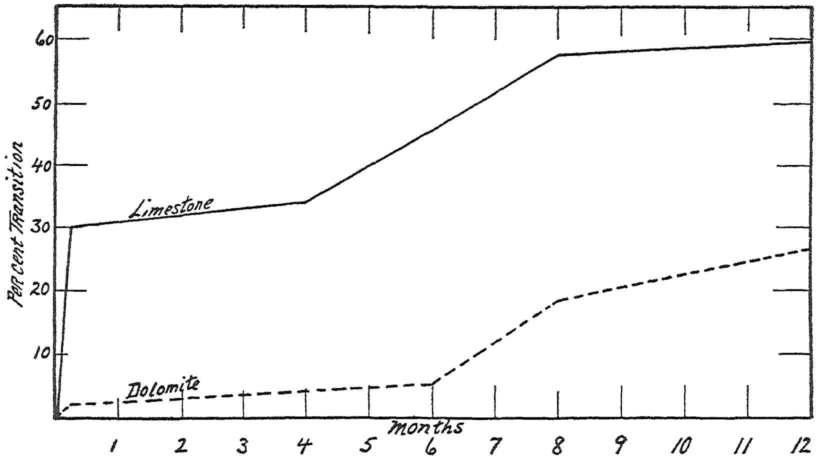

FIG. 1.—Speed of the transitions of citrate-soluble phosphate into the citrate-insoluble form in mixtures with limestone and with dolomite, as measured by progressive decreases in residual carbonates.

Some part of the changes registered by the loss of CO_2 from the dolomite mixtures was probably induced by the more reactive calcite content of the finely ground dolomite, the calcium carbonate content of which was about 10% in excess of the amount required for a molar Ca-Mg ratio of 1:1. It is probable, however, that there was considerable part of the reaction due to the double carbonate, $CaCO_3.MgCO_3$. The ready solubility of the resultant magnesium phosphate and the smaller amount of tri-calcium phosphate derived from the dolomite account for the almost complete solubility of the end-products induced by the admixed dolomite. Another factor is to be considered, namely, the ready reaction between the ammonium citrate solution and limestone, in contrast to the meager reactivity between ammonium citrate and dolomite. Hence, there results a decided decrease in the solvent power of the ammonium citrate when this solution is in contact with suspensions of high-calcic limestone, with a much less extensive diminution of solvent capacity in the case of parallel dolomite suspensions. Furthermore, any amount of tri-magnesium phosphate that could be formed under the imposed conditions would be completely dissolved by the citrate solution.

The wide difference between the actual transitions shown by the maximal carbonate disintegration and phosphate transition registered by the ammonium-citrate determination in the high-calcic limestone mixture is accounted for by the fact that the tri-calcium phosphate formed in this mixture was exceedingly finely divided and probably hydrated, and this near-colloidal and hydrated state imparts to the tri-calcium phosphate formed a solubility far in excess of that registered by ordinary tri-calcium phosphate and especially that found in the fluorine-carrying natural phosphate rock.

The mixtures of Table 1 stood in a room that had an eastern exposure and no steam heat. The temperatures imposed during the days of the summer months were therefore abnormal, whereas the temperatures imposed during the winter days were always materially lower than those of the adjoining rooms. These conditions are reflected in the changes shown in Table 1, and it is indicated that the seasonal temperatures during storing and curing periods will materially affect the speed of the tri-phosphate transitions. When the maximal values of 60% for the limestone mixtures and 26% for the dolomite mixtures are considered, it should be remembered that the amount of P_2O_5 present is more than 3 times that encountered in mixtures of standard superphosphate and also more than would be expected in mixtures of standard treble superphosphate. It should also be stressed that a 74% transition was the maximal tri-phosphate transition previously found when mono-calcium phosphate was agitated with an excess of high-calcic limestone and the resultant transitions to di-calcium phosphate and tri-calcium phosphate were computed from the determined quantities of constantly aspirated CO_2.

SUMMARY

From extended exposures of frequently wetted mixtures of di-calcium phosphate with excesses of limestone and of dolomite of 100-mesh fineness in a humidified atmosphere, it was demonstrated that:

1. Nearly one-third of the theoretical transitions from di-phosphate to tri-phosphate was induced by the high-calcic limestone admixtures within the first week, as against a 60% transition for the 1-year period.
2. The transitions induced by the dolomite additions were much less rapid and extensive than those found for limestone.
3. The "citrate-insoluble" P_2O_5 results obtained by the A. O. A.C. extraction method, as indicative of tri-phosphate transitions, were less than one-half of the maximal registered by the limestone disintegrations, whereas only a small increase in "citrate-insoluble" was registered by the analysis of the dolomite mixtures.

Taken in connection with previous related studies, the results can be interpreted to mean that when standard superphosphate is mixed with more than its full neutralizing equivalent of high-calcic limestone and the mixtures are stored under humid conditions for an extended period of time, a marked decrease in commercial evaluation of the P_2O_5 content of the supplemented material will occur because of the extensive formation of tri-calcium phosphate or "citrate-insoluble". Similar mixtures containing dolomitic limestone acquire only a small content of "citrate-insoluble".

LITERATURE CITED

1. MacIntire, W. H. Dolomite as a fertilizer supplement—its behavior and control. Jour. A. O. A. C., 16 : 589–598. 1933.
2. ————, and Sanders, K. B. The chemical and physical behavior of certain fertilizer salts when mixed with limestone and dolomite. Jour. Amer. Soc. Agron., 30 : 764–70. 1928.
3. ————, and Shuey, G. A. Chemical changes in mixtures of superphosphate with dolomite and with limestone. Ind. and Eng. Chem., 24 : 933–941. 1932.
4. ———— and Shaw, W. M. Reactivity between dolomite and superphosphate components. Ind. and Eng. Chem., 24 : 1401–1409. 1932.
5. Parker, F. W. The importance of calcium and magnesium to the nitrogen and fertilizer industry. Amer. Fert., 76 : No 2, 13. 1932.
6. Pierre, W. H. Determination of equivalent acidity and basicity of fertilizers. Ind. and Eng. Chem., Anal. Ed., 5 : 229–234. 1933.

THE FERTILIZER REQUIREMENT OF HAGERSTOWN SOIL[1]

F. D. Gardner[2]

The best evidence relative to the fertilizer requirements of the Hagerstown soils is afforded by the field experiments at the Pennsylvania State College. The Jordan soil fertility plats, now 52 years old, and the phosphorus plats that have been in progress for 16 years, afford much data relative to the fertilizer requirement, and some relative to changes in requirements, for this soil.

Twenty to 30 years of crop removal along with different systems of manuring and crop rotations must bring about soil changes so that the fertilizer requirements of one decade are sure to be somewhat modified in succeeding years.

Both the old Jordan fertility plats and the more recent phosphate plats are laid out in four tiers of plats and devoted to a 4-year crop rotation consisting of corn, oats, wheat, and mixed clover and timothy. The old plats are 1/8 acre each and the phosphorus plats 1/10 acre each and are long and narrow with permanent grass strips between. They are subject to uniform treatment adapted to the crops grown. Fertilizers, manure, and other treatments are applied to the corn and to the wheat but not to the oats or hay. All operations are as uniform as possible so that the differences in yield may be attributed wholly to the differences in fertilizer treatment.

A chemical analysis of the soil representative of the College farms shows an abundance of potash and a very moderate supply of phosphoric acid, as follows:

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[1] Contribution from the Department of Agronomy, Pennsylvania Agricultural Experiment Station, State College, Pa. Published by authority of the Director of the Station, March 1, 1934, as technical paper No. 639. Also presented at the annual meeting of the Society held in Chicago, Ill., November 1933. Received for publication February 7, 1934.

[2] Professor of Agronomy. The writer acknowledges the helpful suggestions and data on nitrogen losses supplied by Professor J. W. White.

Depth, inches	K_2O	P_2O_5
0 – 9½	3.96	0.102
9½–19	4.42	0.102
19 –42	4.40	0.077

The nitrogen content of the surface 7 inches of soil averages 0.13% with a fairly constant nitrogen-carbon ratio of 1:12.8. A lime requirement survey of Pennsylvania soils made in 1917 by J. W. White showed that only 25% of the Hagerstown soil area was acid as compared to 72% of the entire soil area included in the improved farm lands of the state.[3]

The Jordan soil fertility plats were continued from 1881 to 1921, a period of 40 years, without any changes in fertilizer treatments. On the latter date tiers 2 and 4 were limed and a few plat treatments in these two tiers were changed, but tiers 1 and 3 are still continued with the original treatments. The results show that phosphorus is the first limiting factor in crop production on this soil. Nitrogen alone, potash alone, and a combination of nitrogen and potash without phosphorus has produced very little increase in crop yields, much less than has been produced by phosphorus alone. Notwithstanding this fact, phosphorus alone will not maintain the fertility of the soil.

The addition of potash and phosphorus shows marked increase in yield resulting from the potash and these two elements with clover once in 4 years in each rotation are sufficient to maintain the fertility of the soil as shown by the results over a period of 50 years. There is evidence, however, that some lime will be needed in order to maintain a favorable reaction of the soil for optimum crop production. On the old plats phosphorus has been applied at the rate of 48 pounds of P_2O_5 per acre on alternate years. It is evident that this amount was not sufficient for best and most economical yields. This led to a phosphorus experiment, started in 1916, on which fertilizers were first applied in 1920 so that results from three 4-year rotations are now available. In this test different forms and amounts of phosphorus are used with and without manure and with and without lime.

Table 1 gives the sum of the average annual acre yields of the grain, straw, stover, and hay in pounds per acre for each rotation by 4-year periods for superphosphate. From this table it will be noted that a marked increase in yield has been secured for each additional 150 pounds of 16% superphosphate up to 600 pounds per acre when this material has been used along with a standard amount of 130 pounds of nitrate of soda and 100 pounds of muriate of potash. While this test has not been going sufficiently long to draw final conclusions, it certainly points the direction and indicates that large amounts of phosphorus may be applied on this soil for a general crop rotation with good profit.

On the old Jordan fertility plats nitrogen in different forms and amounts has been applied throughout the enitre time of the test. These show that nitrogen on this soil and for the crops grown is rela-

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[3] WHITE, J. W. Lime requirement of Pennsylvania soils. Pa. Agr. Exp. Sta. Bul. 164. 1920.

TABLE 1.—*Effect of different amounts of 16% superphosphate when applied with 130 lbs. of nitrate of soda and 100 lbs. of muriate of potash on the Pennsylvania phosphate plats, 1921–32.*

Superphosphate, lbs.	Plat No.	Sum of average annual acre yields of all crops in a rotation by 4-year periods, lbs.		
		1st 4 yrs.	2nd 4 yrs.	3rd 4 yrs.
None	10	11,518	8,605	7,650
150	3	12,482	11,459	10,911
300	4	13,401	13,181	12,859
450	7	15,390	14,631	14,353
600	9	16,583	15,900	15,460
Gains for Each Succeeding 150 lbs. Superphosphate				
	3	964	2,854	3,261
	4	919	1,722	1,948
	7	1,989	1,450	1,494
	9	1,193	1,269	1,107
Total	—	5,065	7,295	7,810

tively unimportant. The larger the amount applied the greater the loss incurred. The beneficial effect for the smallest amount has been justified for wheat but not for corn. Furthermore, the different forms have affected the reaction of the soil and sulfate of ammonia has increased acidity in proportion to the amount used until, with large amounts, the soil has become nearly sterile to the crops grown.

At the beginning of the experiment the plat soils were very fertile as measured by the early yields. During the first 18 years (1881–1899), there occurred a rapid loss of nitrogen on all plats and each plat readjusted itself to conform to the crop, cultural, and manurial treatments established in 1881. During this early period of readjustment the loss of nitrogen (in excess of that removed in crops) was 81% of the total lost during the 40 years (1881–1921). Of the total nitrogen lost from the PK plats from 1881 to 1921, 85% occurred during the first 18 years. In a like manner the loss on the plats treated with nitrate of soda plus PK was 92%. From 1889 to 1910 all plats approached a state of equilibrium in accordance with the respective treatments. The annual loss or gain of nitrogen per acre from representative plats by periods are shown in Table 2.

TABLE 2.—*Annual gain or loss of nitrogen from the soil of certain of the Jordan soil fertility plats, lbs. per acre (2,000,000 lbs. of soil).**

Plat No.	Treatment	1881–99	1899–1910	1910–21
24	No fertilizer	— 59.9	— 5.5	+ 1.0
25, 29	P K	— 30.3	+ 20.8	+ 19.3
26	P K + 24 N	— 41.1	+ 10.9	+ 21.1
27	P K + 48 N	— 54.7	+ 8.0	+ 3.6
28	P K + 72 N	— 62.9	— 10.5	— 1.1

*Nitrogen in terms of nitrate of soda. Reported by White and Holben in this JOURNAL, 23: 732–734. 1931.

These facts relative to the loss of nitrogen from the soil and the indifferent effect of inorganic nitrogen in restoring it further justifies the advice that nitrogen should be applied for growing crops at the time needed by the crop and in amounts no more than sufficient for the crop. An excess will not carry over for the next year except as stored in crop residues.

During the first two rotations of the old plats, lime was not a limiting factor. In the course of 40 years, however, it became a factor on many of the plats. Table 3 shows the effect of burnt lime applied at the rate of 2 tons per acre once each 4 years along with 6 tons of barnyard manure, twice in the same period of time, when compared with manure without lime. During the first 8 years, the yields were practically the same, but for the second and succeeding 8-year periods up to the last one, the difference in yield increased at fairly regular amounts up to 3,728 pounds during the last period, or an increase of 25.5% attributable to lime.

TABLE 3.—*Sum of average annual acre yields of all crops in the rotation in pounds, also the annual gain attributed to lime applied once each 4 years, results by 8-year periods, Jordan soil fertility plats.*

Period	Treatment*		Difference in favor of liming	Percentage increase from liming
	6 tons manure	6 tons manure + lime		
1882–1889	17,249	17,306	57	0.3
1890–1897	18,090	18,974	884	4.9
1898–1905	16,782	17,788	1,006	6.0
1906–1913	17,620	19,417	1,797	10.2
1914–1921	16,522	19,342	2,820	17.0
1922–1930	14,546	18,274	3,728	25.5

*Limestone requirement for 6 tons of manure without lime: 1906–13 = 806 lbs. per acre; 1914–21 = 2,278 lbs. per acre; 1922–30 = 3,153 lbs. per acre.

Lime applied at the end of 40 years to those plats that were most acid as a result of many applications of sulfate of ammonia has brought the yield back to a point above what it was in the beginning. The average annual yield per acre in a rotation for the sulfate of ammonia plats was increased to considerably over 19,000 pounds of produce or a yield higher than for any other plats in the limed tiers during the period of 1922 to 1930, inclusive. This is shown in Table 17 of Bulletin 264 of the Pennsylvania Agricultural Experiment Station.

On this soil, potash has very little effect when used in the absence of phosphorus. When used with phosphorus large increases in yield and a good profit has resulted even when used at the rate of 200 pounds of muriate of potash per acre on alternate years. Where lime is applied occasionally to maintain a favorable soil reaction, the beneficial effect of the potash continues. More was used than was necessary, consequently, when the phosphorus plats were laid out, three plats in each tier were included for applications of 50, 100, and 150 pounds of muriate of potash per acre, respectively, along with a standard amount of nitrogen and phosphorus. The increases in yield with increased amounts of potash indicate that small applications are likely to be sufficient.

SUMMARY

In a 4-year grain rotation such as that followed in this experiment, liberal dressings of available phosphorus and potassium on limed land are sufficient to maintain the productivity of Hagerstown soil.

Nitrogen supplied by the clover crop residues together with that fixed by non-symbiotic micro-organisms has been shown to be sufficient to meet the needs of the grain crop included in the rotation.

The nitrogen supply of the soil is not permanently increased by applying inorganic nitrogen. It will be influenced, however, by increasing crop yields and the return of more crop residues to the soil. Even this may be overcome by the accelerating effect of such nitrogen on the decomposition of crop residues.

THE INTERRELATIONS OF VARIOUS PROBABILITY TABLES AND A MODIFICATION OF STUDENT'S PROBABILITY TABLE FOR THE ARGUMENT "t"[1]

J. R. LIVERMORE[2]

Since 1900 several different types of tables of the probability integral have been introduced. This multiplicity of tables has caused considerable confusion and the experimentalist is often at a loss to know which table he should use and how the probability values or odds should be interpreted. It would seem advisable, therefore, to establish the interrelations that exist among the tables in an endeavor to avoid further confusion in the minds of many research workers.

The fact that in one major group of tables the probability values are equivalent to the area ½ (1+a) and that in the other group the probability values are derived from the area "a", is not generally recognized. The odds in tables of the first group are determined by the ratio of ½ (1+a) to ½ (1−a) and in the second group by the ratio of "a" to (1−a), where "a" equals the middle area of the curve. Tables in the first group are often referred to as one-tailed tables and those in the second group as two-tailed tables.

Some of the probability tables and tables of odds in rather general use at one time or another are classified as follows:

One-tailed tables:
- Wood (11)[3] Table V
- Pearson (8) Table II
- Student (9) Table for "z"

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[1] Contribution from the Department of Plant Breeding, Cornell University, Ithaca, N. Y. Paper No. 204. Received for publication January 24, 1934.

[2] Research Assistant Professor of Plant Breeding.

[3] Figures in parenthesis refer to "Literature Cited," p. 672.

Love (6) Modification of Student's Table for "z"
Student (10) Table for "t"
Livermore (4) Modification of Student's Table for "t"

Two-tailed tables:
Wood (11) Table IV
Pearl and Miner (7) Table I
Davenport (1) Table IV
Love (5) Modification of Davenport's Table IV
Livermore (3) Modification of Pearson's Table II
Fisher (2) Table for "t"

The interpretation of the probability values, or of the odds derived from the probability values, is distinctly different for the two groups. Odds derived from tables of the one-tailed group are to be interpreted as some number to 1 against the occurrence of so great or greater a deviation in one direction only being due to chance or sampling error alone. When odds are obtained from tables in the two-tailed group they are to be interpreted as some number to 1 against the occurrence of so great or greater a deviation in either direction being due to chance or sampling error alone.

The odds from tables in the first group will be exactly 2 times plus 1 as great as the odds, for any argument of the same magnitude, from tables in the second group. The constant relationship of "2 times plus 1" holds for all values of the particular argument where no interpolation is necessary. Of course, since all probability values or areas involve a curving line, any straight-line interpolation must result in error, and the "2 times plus 1" relationship will not hold true exactly.

Specific examples may help to demonstrate the "2 times plus 1" relationship. Assume that the argument "x/σ" from an experiment equals 2.00. Using Table II from Pearson (8) as representative of the one-tailed tables and Table IV from Davenport (1) as representing two-tailed tables, the probability values are as follows:

For $x/\sigma = 2.00$
From Pearson $P = .9772499$ $1-P = .0227501$ Odds = 42.956
From Davenport $P = .9545$ $1-P = .0455$ Odds = 20.978
$(20.978 \times 2) + 1 = 42.956$

For $x/\sigma = 1.33$
From Pearson $P = .9082409$ $1-P = .0917591$ Odds = 9.898
From Davenport $P = .8165$ $1-P = .1835$ Odds = 4.449
$(4.449 \times 2) + 1 = 9.898$

And if one uses Student's (10) table for "t" to represent the first group, or one-tailed tables, and Fisher's (2) table for "t" to represent the second group, or the two-tailed tables, the same "2 times plus 1" relationship is established by this example:

For $t = 2.2$ $n = 11$
From Student $P = .975$ $1-P = .025$ Odds = 39
From Fisher $P = .95$ $1-P = .05$ Odds = 19
$(19 \times 2) + 1 = 39$

For $t = 3.5$ $n = 7$
From Student $P = .995$ $1-P = .005$ Odds $= 199$
From Fisher $P = .99$ $1-P = .01$ Odds $= 99$
$(99 \times 2) + 1 = 199$

Since the "2 *times plus* 1" relationship holds true for all tables, it is possible to eliminate half the tables now in common use. If one has a two-tailed table and desires to determine the significance of a deviation in one direction only, then the odds in the two-tailed table are doubled and 1 is added to that product to furnish the desired odds. Conversely, if one should have a one-tailed table but may wish to determine the significance of a deviation in either direction, then by subtracting 1 from the odds and dividing the remainder by 2 the desired odds are obtained. Similarly, if dealing with probability values one would double the "improbability" value from a one-tailed table and subtract that value from 1 to determine the probability that would have been obtained from a two-tailed table. Conversely, halving the "improbability" value obtained from a two-tailed table and subtracting that value from 1 would result in the probability value as from a one-tailed table.

Another classification of these tables is made on the basis of the argument with which one enters the table of probabilities, whether that argument be "x", "x/σ", "t", "z", or some other. There are two general divisions and the majority of the tables fall into the first division, for which the argument is the ratio of the mean difference to the standard error of that mean difference. Some of the symbols used to designate the ratio are "x", "x/σ", "D/σ_M", "D/E", Fisher's "t", and Student's "t". There are minor differences, to be sure, such as dividing "σ" by the $\sqrt{n'-1}$ instead of the $\sqrt{n'}$, and so on, but essentially the arrangement of the tables into the two divisions is permissible. The tables by Pearson (8), Student (10), Livermore (3, 4), Pearl and Miner (7), Davenport (1), and Fisher (2) belong in this division. The tables of odds prepared by Wood (11) and Love (5) also are included in this division with the qualification that the ratio of the mean difference to its standard error has been multiplied by .6745 and the symbol "D/PE" has been used to designate the argument.

The argument for the tables in the second division is the ratio of the mean difference to the standard error of a single difference. The table of probabilities for argument "z" prepared by Student (9), and Love's (6) modification of it, are the only tables in this division.

The third classification of the probability tables depends upon the type of curve that was integrated to furnish the probability integral values. Again the several tables may be divided into two major groups. Those tables derived from the normal curve for infinite number constitute the first group and the tables derived from the modified normal curve for small numbers form the second group. The tables in the first group are those of Wood (11), Pearson (8), Pearl and Miner (7), Davenport (1), Love (5), and Livermore (3). In the second group, those for small numbers, are the tables by Student (9, 10), Love (6), Livermore (4), and Fisher (2).

TABLE 1.—*Odds for certain t values.*

t	m= 1 m′= 2	2 3	3 4	4 5	5 6	6 7	7 8	8 9	9 10	10 11	11 12
.1	1	1	1	1	1	1	1	1	1	1	1
.2	1	1	1	1	1	1	1	1	1	1	1
.3	1	2	2	2	2	2	2	2	2	2	2
.4	2	2	2	2	2	2	2	2	2	2	2
.5	2	2	2	2	2	2	2	2	2	2	2
.6	2	2	2	2	2	3	3	3	3	3	3
.7	2	3	3	3	3	3	3	3	3	3	3
.8	3	3	3	3	3	3	3	3	3	4	4
.9	3	3	4	4	4	4	4	4	4	4	4
1.0	3	4	4	4	5	5	5	5	5	5	5
1.1	3	4	5	5	5	5	5	6	6	6	6
1.2	4	5	5	6	6	6	6	7	7	7	7
1.3	4	5	6	7	7	7	8	8	8	8	8
1.4	4	6	7	8	8	8	9	9	9	9	10
1.5	4	6	8	9	9	10	10	11	11	11	11
1.6	5	7	9	10	11	11	12	12	13	13	13
1.7	5	8	10	11	12	13	14	15	15	16	16
1.8	5	8	11	13	14	15	16	17	18	19	19
1.9	5	9	12	14	16	18	19	20	21	22	23
2.0	6	10	13	16	19	21	22	24	25	26	27
2.1	6	11	15	18	21	24	26	28	30	31	33
2.2	6	12	16	21	24	27	30	33	35	37	39
2.3	7	12	18	23	28	32	35	39	42	44	47
2.4	7	13	20	26	31	37	41	45	49	52	56
2.5	7	14	22	29	36	42	48	53	58	63	67
2.6	8	15	24	32	40	48	55	62	68	75	80
2.7	8	17	26	36	46	55	64	73	81	88	96
2.8	8	18	28	40	52	63	74	85	95	105	115
2.9	8	19	31	44	58	72	86	100	113	126	138
3.0	9	20	34	49	66	82	99	117	132	148	166
3.1	9	21	37	54	74	93	114	136	155	178	195
3.2	9	22	39	60	82	107	132	158	184	212	237
3.3	10	24	43	66	92	121	151	184	216	249	285
3.4	10	25	46	73	103	138	174	212	255	293	332
3.5	10	26	50	80	115	155	199	249	293	344	399
3.6	11	28	53	87	127	174	226	285	344	416	475
3.7	11	29	57	95	142	199	262	332	399	475	555
3.8	11	31	61	103	158	221	293	384	475	587	666
3.9	12	32	66	113	174	249	344	434	555	666	832
4.0	12	34	70	122	191	277	384	499	624	768	999
4.1	12	36	75	134	212	311	434	587	768	908	1110
4.2	12	37	80	146	237	356	499	666	832	1110	1428
4.3	13	39	85	158	255	399	555	768	999	1249	1666
4.4	13	41	91	171	285	434	624	908	1110	1428	1999
4.5	13	42	97	184	311	475	713	999	1428	1666	1999
4.6	14	44	102	199	344	555	832	1110	1666	1999	2499
4.7	14	46	109	212	369	587	908	1249	1666	2499	3332
4.8	14	48	115	232	416	666	999	1428	1999	2499	3332
4.9	15	50	122	249	454	713	1110	1666	2499	3332	4999
5.0	15	52	129	269	475	832	1249	1999	2499	3332	4999
5.1	15	54	136	285	525	908	1428	1999	3332	4999	4999
5.2	16	56	144	302	587	999	1666	2499	3332	4999	9999
5.3	16	58	151	332	624	1110	1666	2499	4999	4999	
5.4	16	60	160	356	666	1249	1999	3332	4999	4999	
5.5	16	62	168	369	713	1249	1999	3332	4999	9999	
5.6	17	65	178	399	768	1428	2499	3332	4999		
5.7	17	67	184	434	832	1666	2499	4999	9999		
5.8	17	69	195	454	908	1666	3332	4999			
5.9	18	71	203	475	999	1999	3332	4999			
6.0	18	74	216	525	1110	1999	3332	4999			

TABLE I.—(*Continued*).

t	m=12 m'=13	13 14	14 15	15 16	16 17	17 18	18 19	19 20	20 21	∞
.1	1	1	1	1	1	1	1	1	1	1
.2	1	1	1	1	1	1	1	1	1	1
.3	2	2	2	2	2	2	2	2	2	2
.4	2	2	2	2	2	2	2	2	2	2
.5	2	2	2	2	2	2	2	2	2	2
.6	3	3	3	3	3	3	3	3	3	3
.7	3	3	3	3	3	3	3	3	3	3
.8	4	4	4	4	4	4	4	4	4	4
.9	4	4	4	4	4	4	4	4	4	4
1.0	5	5	5	5	5	5	5	5	5	5
1.1	6	6	6	6	6	6	6	6	6	6
1.2	7	7	7	7	7	7	7	7	7	8
1.3	8	8	8	8	8	8	9	9	9	9
1.4	10	10	10	10	10	10	10	10	10	11
1.5	12	12	12	12	12	12	12	12	12	14
1.6	14	14	14	14	14	15	15	15	15	17
1.7	16	17	17	17	17	18	18	18	18	21
1.8	20	20	20	21	21	21	22	22	22	27
1.9	23	24	25	25	25	26	26	26	27	34
2.0	28	29	30	30	31	31	32	32	33	43
2.1	34	35	36	37	37	38	39	39	40	55
2.2	40	42	43	45	46	47	48	49	49	71
2.3	49	51	52	54	56	57	59	60	61	92
2.4	59	61	64	66	68	70	72	74	75	121
2.5	70	74	78	80	84	86	88	91	93	160
2.6	85	90	94	99	102	107	110	113	115	214
2.7	102	109	115	121	126	131	136	140	144	287
2.8	124	132	140	148	155	160	168	174	181	390
2.9	148	160	171	181	191	199	207	216	226	535
3.0	181	195	207	221	237	249	262	269	285	740
3.1	216	237	255	269	293	311	322	344	356	1032
3.2	262	285	311	332	356	384	399	416	454	1454
3.3	311	344	384	416	434	475	499	525	555	2068
3.4	384	416	454	499	555	587	624	666	713	2967
3.5	454	499	555	624	666	713	768	832	908	4298
3.6	555	624	713	768	832	908	999	999	1110	6284
3.7	666	768	832	908	999	1110	1249	1249	1428	9275
3.8	768	908	999	1110	1249	1428	1428	1666	1666	13830
3.9	908	1110	1249	1428	1666	1666	1999	1999	2499	20789
4.0	1110	1249	1428	1666	1999	1999	2499	2499	2499	31545
4.1	1428	1666	1999	1999	2499	2499	3332	3332	3332	48308
4.2	1666	1999	2499	2499	3332	3332	3332	4999	4999	75187
4.3	1999	2499	2499	3332	3332	4999	4999	4999	4999	117646
4.4	2499	2499	3332	3332	4999	4999	4999	4999	9999	185184
4.5	2499	3332	4999	4999	4999	4999	9999	9999		
4.6	3332	4999	4999	4999	9999	9999				
4.7	3332	4999	4999	9999						
4.8	4999	4999	9999							
4.9	4999	9999								
5.0	4999									
5.1	9999									

A modification of Student's table for t for estimating the mathematical significance of a difference in one direction. Odds calculated from probability values as given in original table: Student, Metron, Vol. V, No.3, 1925. J. R. Livermore, May, 1933.

The convenience of having one probability table that could be used either as a two-tailed table or as a one-tailed table, that could be entered by argument "x/σ" or "z" or "t", and that was equally as useful for those experiments involving large numbers of units as for those based on small numbers, has long been recognized. It is not generally known, however, that just such a probability table has been available for several years. In 1925, Student (10) published in *Metron* an article entitled "New Tables for Testing the Significance of Observations", in which he has tabled the probability integral derived from the "small-number" curve for "t" values from 0.1 to 6.0 by tenth-unit intervals with values for "n" from 1 to 20 (n′ from 2 to 21) by unit intervals and for "n" equal to infinity.

In view of the fact that the use of odds appears to be more general than the use of probabilities, at least in the United States, the writer has modified the form of Student's (10) table by converting the probability values to odds and these odds appear in Table 1. Actual examples may best illustrate the method of calculating "t" and finding the odds for that value. Also these examples will serve to establish the fact that Student's table for "t", and the modification of it, may be used in place of any one or all other tables of probability and of odds discussed in this paper.

Example 1.—In this experiment it is assumed that pairing of observations is permissible and the yield data for two varieties are as follows:

x_1	x_2	D_{1-2}	d	d^2
29.3	20.4	8.9	− .3	.09
21.3	20.2	1.1	−8.1	65.61
30.7	20.1	10.6	1.4	1.96
30.2	23.4	6.8	−2.4	5.76
36.4	23.7	12.7	3.5	12.25
37.4	19.3	18.1	8.9	79.21
35.6	25.1	10.5	1.3	1.69
27.8	18.7	9.1	− .1	.01
24.7	17.4	7.3	−1.9	3.61
36.3	29.6	6.7	−2.5	6.25
		10)91.8		90)176.44
		MD = 9.2		$\sqrt{1.9604}$
				1.400

$$\sigma_{MD} = \sqrt{\frac{\Sigma d^2}{n'(n'-1)}} \qquad \sigma_{MD} = 1.400$$

$$t = \frac{MD}{\sigma_{MD}} \qquad t = 6.57$$

$$n = n'-1 \qquad n = 9$$

From Student (10) for t = 6.57 Column 9–10 P = .999913

.999913/.000087 = Odds = 11493

From Table 1 for t = 6.57 Column 9–10 read Odds = >9999

Example 2.—Suppose that the yield data in example 1 had been derived from an experiment in which pairing of observations was not possible, then

x_1	d_1	d_1^2	x_2	d_2	d_2^2
29.3	−1.7	2.89	20.4	−1.4	1.96
21.3	−9.7	94.09	20.2	−1.6	2.56
30.7	− .3	.09	20.1	−1.7	2.89
30.2	− .8	.64	23.4	1.6	2.56
36.4	5.4	29.16	23.7	1.9	3.61
37.4	6.4	40.96	19.3	−2.5	6.25
35.6	4.6	21.16	25.1	3.3	10.89
27.8	−3.2	10.24	18.7	−3.1	9.61
24.7	−6.3	39.69	17.4	−4.4	19.36
36.3	5.3	28.09	29.6	7.8	60.84
10)309.7		90)267.01	10)217.9		90)120.53
30.97		$\sqrt{2.9668}$	21.79		$\sqrt{1.3392}$

$M_1 = 31.0$ $\sigma_{M_1} = 1.72$ $M_2 = 21.8$ $\sigma_{M_2} = 1.16$

$D_{M_1M_2} = M_1 - M_2$ $\sigma_{D_{M_1-M_2}} = \sqrt{\sigma_{M_1}^2 + \sigma_{M_2}^2}$

$D = 9.2$ $\sigma_D = 2.08$

$t = \frac{D}{\sigma_D}$ $t = 4.4$

$n = n'_1 + n'_2 - 2$ $n = 18$

From Student (10) for t = 4.4 Column 18–19 P = .9998
.9998/.0002 = Odds = 4999
From Table 1 for t = 4.4 Column 18–19 read Odds = 4999

Example 3.—Assume that in an experiment using a large number of plats the x/σ ratio is 2.6 and one wishes to determine the significance of the deviation in one direction, then
From Pearson (8) P = .9953388 1–P = .0046612 Odds = 213.537
From Student (10) P = .9953388 1–P = .0046612 Odds = 213.537
From Livermore (4) in Table 1 for t = 2.6, Column $\propto$ read 214

Example 4.—Using the same experiment as in example 3, suppose one wishes to determine the significance of the deviation in either direction, then
From Davenport (1) P= .99068 1–P = .00932 Odds = 106.296
From Student (10) P= .9953388 1–P = .0046612 and
1–2 (1–P) = P′ = .9906776 1–P′ = .0093224 Odds = 106.269
From Livermore (4) Odds = 214 subtract 1 = 213 213/2 = 106.5

Example 5.—With the same x/σ ratio of 2.6 as in examples 3 and 4, suppose the experiment involved only 10 plats. From Table 1, Column 9–10, opposite t = 2.6 read 68; the odds are 68:1 against so great a deviation in one direction occurring due to chance alone. Subtracting 1 from 68 and dividing by 2, the resulting odds are 33.5:1 and one may say that the odds are 33.5:1 against so great a deviation in either direction occurring due to chance alone.

Example 6.—In an experiment so planned that Student's (9) method of analysis is applicable, and with 10 paired observations, the "z" value is 0.8. It is necessary to change "z" to "t". This is done by multiplying "z" by the $\sqrt{n}$, where "n" is 1 less than the number of paired observations. Then,

From Student (9) $P = .98007$ $1-P = .01993$ Odds = 49.176
From Love (6) For $z = 0.8$, Column 10, read Odds = 49.3
From Livermore (4) $z\sqrt{n} = t = (0.8)(3) = 2.4$
In Table 1 for $t = 2.4$, column 9–10, read odds = 49.0.

The odds are 49:1 that the mean difference is greater than O, or the odds are 49:1 against the occurrence of so great a deviation in one direction being due to chance alone.

In other words, it is quite possible to derive odds from Table 1 which may be interpreted as against deviations in one direction or as odds against deviations in either direction. The table is equally useful for experiments based on a large number or on a small number of units, and it may be entered with Student's argument "z" times the $\sqrt{n'-1}$ as well as with the arguments "x/σ" and "t".

There may be some research workers who would prefer to have finer gradations between the values for "t" than are given in Table 1, or who might prefer the inclusion of odds for "t" values greater than 6.0. It must be realized that odds are not an end in themselves; they are of relative magnitude only. Odds of 30:1 in a particular instance do not indicate that the difference is twice as significant as for odds of 15:1. All that may be said is that with odds of 30:1 the difference is considered mathematically as more significant than a similar difference with odds of 15:1. Increasing the magnitude of the odds implies that a greater proportion of the total area of the curve has been included between the limits established by the magnitude of the argument and the probability that such a difference is due to chance is decreasing or, in other words, the difference is becoming more significant mathematically.

If the investigator must have finer gradations, interpolation will provide the intermediate values. It should be recognized, however, that linear interpolation in any table of probabilities or of odds is open to criticism and is subject to gross error, particularly when such interpolation is made between values near the ends of the curve where the line is curving rapidly. For those who require probability values for "t" greater than 6.0, Student (10) published a supplementary table for high values of "t". The values of "t" from 6.0 to 28.0 are tabled with values of "n" from 3 to 10 (n′ from 4 to 11), together with their respective probability integrals.

LITERATURE CITED

1. Davenport, C. B. Statistical Methods. New York: John Wiley & Sons. Ed. 1. 1899.
2. Fisher, R. A. Statistical Methods for Research Workers. London: Oliver & Boyd. Ed. 4. 1932.
3. Livermore, J. R. Mimeographed laboratory exercises. Cornell University, Plant Breeding Department, 1933 edition. 1933.
4. ————. A modification of Student's Table for "t" for estimating the mathematical significance of a difference. Unpublished data.
5. Love, H. H. Unpublished data.
6. ————. A modification of Student's table for use in interpreting experimental results. Jour. Amer. Soc. Agron., 16: 68–73. 1924.
7. Pearl, R., and Miner, J. R. A table for estimating the probable significance of statistical constants. Maine Agr. Exp. Sta. Bul. 226. 1914.
8. Pearson, Karl. Tables for statisticians and biometricians, Part I. London: Cambridge University Press. Ed. 3. 1930.

9. STUDENT. The probable error of a mean. Biometrika, 6 : 1–26. 1908.
10. ———— New tables for testing the significance of observations. Metron, 5(3) : 18–21. 1925.
11. WOOD, T. B. The interpretation of experimental results. Jour. Board Agr., London, Suppl., 7 : 15–37. 1911.

DEHULLED SEED, GLUME COLOR, AND REACTION TO SMUT IN A CERTAIN OAT CROSS[1]

R. J. GARBER AND M. M. HOOVER[2]

In two earlier papers (2, 3)[3] some evidence was presented which seemed to indicate that the gene for black color was linked with a factor responsible for transgressive susceptibility to smut in the oat cross Black Mesdag x Gopher. In the meantime, certain backcrosses involving this same material have been made and their reaction to a mixture of loose smut (*Ustilago avenae*) and covered smut (*U. levis*) has been determined. The purpose of this paper is to present and discuss the additional data.

MATERIAL AND METHOD

In 1931 certain F_1 plants (Gopher-Black Mesdag) were backcrossed[4] reciprocally to the Gopher parent and other F_1 plants to a white-seeded F_5 descendant (17–10–75–5–1) from the above cross. The F_3 and F_4 progenitors of this F_5 family were somewhat more susceptible to smut than the comparable Gopher parent grown with them, as has been shown (3 p. 955.) The particular F_5 descendant used in the backcross came from the most susceptible F_4 line.

In 1932, 57 plants resulting from the backcrosses F_1 x Gopher and reciprocal, and 86 plants from F_1 x 17–10–75–5–1 and reciprocal were grown in the nursery under smut-free conditions. Seed produced by each of these plants was treated with a mixture of loose and covered smut as in the previous work, except that most of the seed was dehulled before treatment. For comparison some of the seed from certain plants was not dehulled. All the smut-treated oats was seeded in individual plant plats on June 13 and 14. If sufficient seed was available, a strain was planted in four systematically distributed plats, each plat consisting of two rows 5 feet long and 1 foot apart. Twenty seeds individually spaced were planted per row.

Unfortunately, a heavy washing rain occurred about the time the seedlings were emerging and even though the nursery is located on a level tract of land considerable damage was done. This, combined with the fact that the season was rather unfavorable for late-seeded oats, made the seedling and plant mortality unusually high.

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[2] Agronomist and Associate Agronomist, respectively.

[3] Reference by number is to "Literature Cited," p. 680.

[4] The authors are indebted to L. S. Bennett and M. H. Snyder, graduate assistants, for aid in making the crosses.

It has been mentioned that the seeds were treated with a mixture of loose and covered smut. This was done by placing a small quantity of smut spores (held on the end of a spatula) in the envelope containing the seed and then thoroughly shaking the envelope. A mixture of smut spores was used because it was found that Black Mesdag and Gopher, as well as certain of the descendent hybrid strains, gave similar smut reactions to *U. levis* and to *U. avenae*. The separation[5] of loose and covered smut was made on the basis of appearance in the field and also on the basis of microscopic examination of the spores.

REACTION TO LOOSE AND COVERED SMUT

In Table 1 typical data are given which show the reaction of the parents as well as of two F_6 families to loose and to covered smut. It is obvious that no consistent difference was obtained in the percentage of smutted plants between seed inoculated with *U. avenae* and that *inoculated* with *U. levis*, although location in the nursery apparently had an appreciable effect on percentage of infection.

EFFECT OF DEHULLED SEED

It is clear from both Tables 1 and 2 that dehulling the seed before treating with smut increased very materially the percentage of smutted plants. Similar results have been obtained by other investigators.

Another effect of dehulling which has been noted by Bayles and Coffman (1) is also apparent from the examination of the tables just mentioned. Dehulling the seed appreciably increased the mortality of the resultant plants. Even though the same number of dehulled and normal seed of each strain was planted, the number of resultant mature plants was almost without exception the greater from the seed not dehulled. It has been suggested (1) that the increased mortality of the seedlings and plants is due in part to the mechanical injury to the seed during the dehulling process and in part to the increased susceptibility to smut.

In the last two columns of Table 1 the total number of plants for each strain of oats and the percentage reduction of plants from dehulled seed are shown. Black Mesdag, which produced no smutted plants, gave a percentage reduction of 20.7, whereas the other strains, all of which produced some smutted plants, gave percentage reductions of 26.0, 29.8, and 38.7. Similarly, in Table 2, the two second generation descendants of Gopher x F_1 and reciprocal which showed no smut infection produced 28.5% fewer plants from the dehulled seed than from the seed not dehulled. The comparable percentage reduction in number of plants for the eight second generation descendants which showed smut infection was 46.6. The reduction in the number of plants for the four second generation descendants of 17-10-75-5-1 x F_1 and reciprocal, all of which showed some smutted plants, was 50.2%. These data are similar to those obtained by

[5] The writers are indebted to Dr. N. J. Giddings, formerly plant pathologist of the West Virginia Agricultural Experiment Station, for most of the spore examinations.

TABLE 1.—*Reaction of certain strains of oats grown in 1929 to U. avenae and to U. levis.*

Plat No.	Seed treated with	Number of plants	Plants smutted %	Total No. of plants for the strain	Percentage reduction in number of plants
		Black Mesdag			
1	U. avenae	55	0	—	—
9	U. levis	50	0	—	—
17	U. avenae	60	0	—	—
25	U. levis	62	0	227	—
		Black Mesdag*			
2	U. avenae	45	0	—	—
10	U. levis	54	0	—	—
18	U. avenae	35	0	—	—
26	U. levis	46	0	180	20.7
		16–15–68-etc. F_6			
3	U. avenae	61	9.8	—	—
11	U. levis	68	8.8	—	—
19	U. avenae	52	7.7	—	—
27	U. levis	85	8.2	266	—
		16–15–68-etc. F_6*			
4	U. avenae	41	80.5	—	—
12	U. levis	57	78.9	—	—
20	U. avenae	29	65.5	—	—
28	U. levis	36	38.9	163	38.7
		17–10–68-etc. F_6			
5	U. avenae	54	24.1	—	—
13	U. levis	57	15.8	—	—
21	U. avenae	59	8.5	—	—
29	U. levis	61	6.6	231	—
		17–10–68-etc. F_6*			
6	U. avenae	23	82.6	—	—
14	U. levis	47	83.0	—	—
22	U. avenae	45	57.8	—	—
30	U. levis	56	78.6	171	26.0
		Gopher			
7	U. avenae	64	9.4	—	—
15	U. levis	60	5.0	—	—
23	U. avenae	68	8.8	—	—
31	U. levis	56	3.6	248	—
		Gopher*			
8	U. avenae	25	60.0	—	—
16	U. levis	37	48.6	—	—
24	U. avenae	50	26.0	—	—
32	U. levis	62	27.4	174	29.8

*Seed dehulled before treating with smut.

Bayles and Coffman (1), except that the percentage reductions in plants from dehulled seed are considerably greater than was obtained by them.

TABLE 2.—*The reaction to smut of second generation descendants from certain backcrosses in oats grown in 1933.*

1932 row No.	Parent plant	From dehulled seed		From seed not dehulled	
		No. of plants	Percentage of plants smutted	No of plants	Percentage of plants smutted
		17–10–75–5–1 x F_1			
2	1	32	12.5	77	0
2	5	41	7.3	73	1.4
4	4	28	3.6	65	1.5
		F_1 x 17–10–75–5–1			
23–24	8	33	18.2	54	0
		Gopher x F_1			
28	2	30	13.3	52	7.7
29	1	32	18.7	81	2.5
33	1	49	10.2	65	0
38–39	5	52	0	65	0
40	2	48	8.3	78	1.3
		F_1 x Gopher			
41–42	6	46	54.4	84	4.8
44	3	41	0	65	0
45–46	5	53	22.6	82	4.9
45–46	7	19	26.3	65	0
47	1	29	3.5	66	0

INHERITANCE OF GLUME COLOR

The glumes of Black Mesdag range from dark brown to black and those of Gopher are white. Of the 57 backcrossed seed obtained from Gopher x F_1 and reciprocal, 27 produced plants with dark seed and 30 produced plants with white seed. The 86 plants from the backcross 17–10–75–5–1 x F_1 and reciprocal were classified into 48 with dark glumes and 38 with white, a deviation of 5 ± 3.1 from the expected 1:1 ratio. These backcross data corroborate the conclusion from an earlier analysis (2) based on F_3 material, namely, that glume color was controlled by a single factor difference in the Gopher-Black Mesdag cross. Four of the 57 plants from the backcross Gopher x F_1 and reciprocal and 6 of the 86 plants from the backcross 17–10–75–5–1 x F_1 and reciprocal produced progenies with too few plants to be of value in the analysis of inheritance of reaction to smut and are omitted from Tables 3 and 4.

INHERITANCE OF REACTION TO SMUT

The Black Mesdag and Gopher parents, as well as the 17–10–75–5–1 strain used in one of the backcrosses, were grown from dehulled and smutted seed in several short rows distributed throughout the nursery. The Black Mesdag produced no smutted plants. The Gopher parent for some unknown reason gave somewhat fewer smutted plants than expected, particularly in view of the fact that the seed was dehulled before treatment with smut. Only 13 individuals, or 9.2% of the 141 Gopher plants, were smutted. On the other hand, the 17–10–75–5–1 strain of oats showed a consistently high infection. Seventy-two out of a total of 161, or 44.6%, of the plants were smutted. It will be recalled that in comparable tests 17–10–75–5–1 has uniformily shown greater susceptibility to smut than has Gopher.

The frequency distributions of number of plants per family descendent from the backcrosses and analyzed for their reaction to a mixture of loose and covered smut are shown in Table 3.

TABLE 3.—*Frequency distributions of number of plants per family.**

Name	Number of plants per family							
	8–15	16–20	21–30	31–40	41–50	51–60	61–70	Total
17–10–75–5–1 x F_1 and reciprocal....	7	12	21	22	12	6	–	80
Gopher x F_1 and and reciprocal....	2	2	9	14	13	11	2	53

*The smut reactions of the families are shown in Table 4.

The greatest danger of error in classification with respect to smut reaction is in the highly resistant or immune families. The 12 families from the 17–10–75–5–1 backcross classed as free from smut (Table 4) produced the following number of approximately mature plants per family: 55, 35, 33, 26, 25, 24, 22, 19, 17, 17, 17, and 16. The similarly classified 12 families from the Gopher backcross contained 61, 52, 52, 46, 46, 41, 38, 33, 30, 29, 18, and 8 plants. The family with only eight plants from dehulled seed produced 65 smut-free plants from seed not dehulled, and for this reason is included in the study. While the number of plants per family in some cases is not as great as might be desirable, it should be borne in mind that all the material shown in Tables 3 and 4 came from seed that was dehulled before treating with smut spores.

In the upper half of Table 4 the smut reaction of the second generation families descendent from the backcross 17–10–75–5–1 x F_1 and reciprocal are shown, and in the lower half of the table may be found the smut reaction of similar families from the backcross Gopher x F_1 and reciprocal. No difference in reaction was found between reciprocals so they were grouped together.

Considering the families descendent from the 17–10–75–5–1 backcross, it is apparent that a rather distinct bimodal distribution is obtained with respect to percentage of smutted plants; one distribution ranges between 0 and 27.5 and the other between 27.5 and 67.5. On the other hand, there are only four of the families coming from the Gopher backcross which gave percentages of smutted plants greater than 30.0. In each group of descendants there were 12 families that did not show any smutted plants.

In an earlier paper (3) it was suggested that the genotypes of the parents used in these crosses were as follows: Black Mesdag, RR ii; Gopher, rr II. The dominant R factor carried by Black Mesdag

TABLE 4.—*The percentage of smutted plants among second generation descendants grown in 1933 from certain backcrosses classified with respect to color of seed planted.**

Color of Lemma	Class centers in percentage of smutted plants															
	17-10-75-5-1 x F_1 and Reciprocal															
	0	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	Total
Black	7	7	5	4	2	3	1	3	6	2	1	2	–	–	1	44
White	5	4	7	3	1	3	2	2	1	4	–	2	–	1	1	36
Total	12	11	12	7	3	6	3	5	7	6	1	4	0	1	2	80
	Gopher x F_1 and Reciprocal															
	0	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	Total
Black	6	1	3	4	2	5	2	–	1	–	–	1	–	–	–	25
White	6	8	4	3	2	2	1	1	–	–	–	1	–	–	–	28
Total	12	9	7	7	4	7	3	1	1	0	0	2	–	–	–	53

*All seed dehulled and treated with a mixture of loose and covered smut before planting.

gives high resistance, if not immunity to both loose and covered smut and the I factor carried by Gopher acts as an inhibitor to r or likewise is a factor for resistance but less potent than the R factor. If this hypothesis were correct, rr ii individuals should show greater susceptibility than the Gopher parent and breed true. The strain 17–10–75–5–1 was selected to represent this genotype. The four types of backcrossed seed that would be produced from each of the following backcrosses and their breeding nature with respect to smut reaction would be as follows:

Cross	Genotype of first generation	Breeding nature of second generation
F_1 x 17–10–75–5–1		
Rr Ii x rr ii	RrIi	1/16 highly susceptible
	Rrii	¼ highly susceptible
	rrIi	¼ highly susceptible
	rrii	all highly susceptible
F_1 x Gopher		
Rr Ii x rr II	RrIi	1/16 highly susceptible
	RrII	¼ same susceptibility as Gopher
	rrII	all same susceptibility as Gopher
	rrIi	¼ high susceptible

On this basis approximately one-fourth of the families from the 17–10–75–5–1 backcross should be highly susceptible to smut. No equally susceptible families would be expected from the Gopher backcross families. As a matter of fact, it probably is impossible to distinguish accurately between the families coming from rrIi and rrii parent plants without further analysis. If it is assumed that 6 of the families of the 17–10–75–5–1 backcross with percentages of smutted plants in excess of 30 came from rrIi plants (the same relative number as occurred among the families from the Gopher backcross), then the remaining families would have come from rrii plants. The number of such families, 20, is precisely the number that would be expected on the suggested genetic basis. These data agree with those previously reported in showing that transgressive susceptibility for smut infection has occurred.

It is also apparent from the above genetic scheme that families without smutted plants would not be expected from either backcross. The fact that several families were found without smutted plants is perhaps not surprising when one considers that even the most susceptible lines (rrii) showed an average of less than 50% and the Gopher genotype less than 10% smutted plants. The families so classified probably came frrom RrIi and RrII parental plants. For an accurate determination of the manner of inheritance of smut reaction in this backcross material, another generation would have to be grown. However, the purpose here is not to analyze the inheritance of smut reaction for that has already been done with more suitable material.

GLUME COLOR AND SMUT REACTION

It has been pointed out that the 17–10–75–5–1 strain gave an average percentage of smutted plants of 44.6 with a range of 28.6 to 71.4% among the eight plats distributed throughout the nursery. Of the 80 families (Table 4) descendent from the 17–10–75–5–1 back cross, 26 produced average percentages of smut in excess of 30, whereas from the Gopher backcross 4 such families were obtained.

If the black color gene of Black Mesdag were linked with the i factor, one would expect to obtain a greater number of highly susceptible families coming from black seed than from white seed. As a matter of fact, of the families from the 17–10–75–5–1 backcross that may legitimately be classified as highly susceptible to smut, 15 came from black-seeded and 11 from white-seeded parents. Of the similarly classified families from the Gopher backcross, two came from black and two from white seeds. No evidence for a close linkage is apparent from these data.

SUMMARY AND CONCLUSIONS

The oat varieties Black Mesdag and Gopher, as well as certain descendent lines from hybrids between them, gave similar smut reactions to both *U. levis* and *U. avenae*.

Dehulling the seed before treatment with smut spores very materially increased infection and also increased mortality among the resultant seedlings and plants.

Eighty second generation descendent families from the backcross 17–10–75–5–1 x F_1 and reciprocal and 53 similar families from the Gopher x F_1 backcross and reciprocal were grown under smut epidemic conditions. The data corroborated those obtained earlier with respect to inheritance of color of glume and to some extent the inheritance of smut reaction. The backcrosses gave no significant evidence of a linkage between the gene for black glumes and the gene responsible for increased susceptibility to smut, although a slight predominance (15 from black and 11 from white seed) of highly susceptible families came from black seeds in one of the backcrosses.

LITERATURE CITED

1. BAYLES, B. B., and COFFMAN, F. A. Effects of dehulling seed and of date of seeding on germination and smut infection in oats. Jour. Amer. Soc. Agron., 21 : 41–51. 1929.
2. GARBER, R. J., GIDDINGS, N. J., and HOOVER, M. M. Breeding for disease resistance with particular reference to the smut of oats. Sci. Agr., 9 : 103–115. 1928.
3. ————, ————, ————. Transgressive segregation for susceptibility to smut in an oat cross. Jour. Agr. Res., 39 : 953–962. 1929.

THE COMPARATIVE COLD RESISTANCE OF SPRING SMALL GRAINS[1]

G. L. PELTIER AND T. A. KIESSELBACH[2]

With the installation of control equipment for the study of hardiness in crop plants at the Nebraska Agricultural Experiment Station in 1927 (3)[3], the evaluation of crops and varieties as to cold endurance has been facilitated. Several papers reporting the comparative cold resistance of alfalfas and winter wheats, with methods for such determinations, have been issued from this Station (1, 3, 4, 5, 6, 7,). With the exception of a publication by Martin (2) on the relative cold resistance of Pacific Coast spring wheats, no investigations with spring small grains under controlled conditions have been reported in America, although scattered through the agronomic literature one may find statements based on field observations that a variety of spring wheat, oats, or barley appeared to be more resistant to spring frosts than other varieties of the same crop. Such information would seem to have importance wherever early sown spring grain is subject to injury from freezing.

It was the purpose of this investigation to adapt the methods already developed for measuring cold resistance in alfalfa and winter wheat to spring small grains and to determine not only the relative rating of spring wheat, oats, and barley as to cold endurance, but also to ascertain whether varietal differences may occur within these crops. Tests were included of the germinative response of these different varieties at various temperatures.

METHODS

Based on previous experience and on technic studies herein reported, the following standardized procedure was used in growing, hardening, and testing the seedling plants under investigation. The seedlings were grown in cypress flats (15 x 18 x 6 inches). Preliminary results had indicated less variability in these than in clay pots. Usually, six rows of 30 seeds each were sown in a flat. The soil consisted of a finely shredded sod to which some sand was added. This mixture was uniform in texture and high in fertility. The plants were grown to the desired stage in a greenhouse held at a temperature near 20°C, and were then transferred to the hardening chamber for a period of 7 or 9 days. The soil was brought to a high and uniform moisture content on the day previous to freezing. The seedlings were then exposed in the freezer room at an average temperature of approximately -10°C for 8 hours. This degree of cold exposure had been suggested by preliminary tests as most suitable for these plant and soil conditions. After freezing, the seedlings were moved to the

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[2] Plant Pathologist and Agronomist, respectively. Acknowledgment is given to Elvin F. Frolik for assistance in these studies.

[3] Figures in parenthesis refer to "Literature Cited," p. 686.

warm greenhouse and actual survival counts were made 2 weeks later. All experiments were performed during the months of February, March, and April under natural light conditions.

STUDIES OF EXPERIMENTAL TECHNIC OF HARDINESS TESTS WITH SPRING SMALL GRAINS

A number of tests have been made to determine the best procedure in controlled varietal hardiness studies. These bear on the questions of influence of age and stage of development on the resistance of seedlings to cold, and the comparative results from continuous and intermittent low temperatures during the hardening period.

INFLUENCE OF AGE AND STAGE OF DEVELOPMENT ON RESISTANCE OF SEEDLINGS TO COLD

Seedlings just emerging from the soil or in the one-leaf stage were found materially more resistant to cold than seedlings in the two- and three-leaf stages. Seedlings in or past the 4-leaf stage were likewise more resistant to cold than those of intermediate development. These conclusions were drawn from the following tests.

Two varieties each of oats, barley, and spring wheat were sown in flats at four successive 3-day intervals and grown in a warm greenhouse. To avoid variation in cold exposure when placed in the freezing chamber, the varieties were so planted that they occurred with equal frequency in the various positions within the 12 replicate flats. Fifteen days after the first sowing all flats were transferred to the hardening chamber and held for 9 days at a temperature of 2° to 4° C. They were then exposed to a temperature averaging −10° C for 8 hours. After freezing, the plants were removed to the warm greenhouse and 2 weeks later survival counts were made. The percentages of survival of the different varieties at the various ages and stages of development are shown in Table 1.

Apparently, under the conditions of the experiment, seedlings 15 days after planting and in the late third-leaf stage were most susceptible to cold. Up to this stage of development the resistance to cold decreases progressively with the increased age and size of the seedling. Perhaps a plausible explanation of this phenomenon would be that seedlings are progressively more susceptible to cold as the food reserve of the endosperm becomes exhausted. Somewhat greater differences in cold resistance between oats and barley varieties were exhibited as the time of endosperm depletion was approached. Previous tests have indicated that seedlings beyond this stage are again somewhat more resistant to cold. Apparently, the seedlings grown for 15 days in a warm greenhouse and hardened for 9 days prior to an 8-hour exposure to a temperature of about −10° C will yield the greatest differential varietal response to cold.

CONTINUOUS VS. INTERMITTENT HARDENING TEMPERATURES

Under field conditions the young growing plants are likely to be subjected to intermittent temperatures of relatively low and high

TABLE 1.—*Influence of age and stage of development on the ability of spring small grains to resist cold.**

Variety	Percentage survival after indicated age previous to hardening†				Number of leaves and plant height in cm when placed in the hardening chamber			
	15 days	12 days	9 days	6 days	15 days	12 days	9 days	6 days
				Oats				
Nebr. 21...	29	44	67	89	3 (21)	3 (15)	2 (11)	2 (10)
Kanota....	44	57	75	93	3 (21)	3 (15)	2 (11)	2 (10)
Average....	37	51	71	91	3 (21)	3 (15)	2 (11)	2 (10)
				Barley				
Trebi......	32	69	70	96	3 (24)	3 (19)	2 (13)	2 (11)
Spartan....	48	70	80	92	3 (28)	3 (20)	2 (13)	2 (13)
Average....	40	70	75	94	3 (26)	3 (20)	2 (13)	2 (12)
				Spring Wheat				
Ceres......	38	62	76	96	3 (27)	3 (22)	2 (15)	2 (12)
Hope......	39	63	75	97	3 (27)	3 (23)	2 (16)	2 (13)
Average....	39	63	76	97	3 (27)	3 (23)	2 (16)	2 (13)
				Summary				
All crops...	39	61	74	94	3 (25)	3 (19)	2 (13)	2 (12)

*All plants hardened uniformly for 9 days at 2° to 4° and exposed for 8 hours to a temperature of —10° C. Average of 12 replications, each replication consisting of about 30 plants of each variety at each stage of development.

†The standard error of any varietal mean was 4.2, 4.2, 3.2, and 1.7, respectively, for plants 15, 12, 9, and 6 days of age previous to hardening.

degree during the night and day, respectively. To determine the comparative effects of fluctuating and constant temperatures in the hardening of seedling plants, the following test was made. Two varieties of each of the three spring grains were grown in each of 24 flats for a period of 15 days in the warm house. Half of the flats were then placed in the hardening chamber for 9 days and held at a constant temperature of 2° to 4° C. The second lot was held in the warm greenhouse during the day and in the hardening chamber during the night for the same period. All were then exposed for 8 hours to a temperature averaging —9°C. The percentage of survival for the 12 replications after 2 weeks recovery in the warm greenhouse, together with the stage of development of the seedlings just prior to freezing, are given in Table 2.

It will be noted that the alternating high and low temperatures were somewhat less effective in hardening the plants. With four of the varieties the percentage of surviving plants was approximately 10% less, whereas with Nebr. 21 oats and Hope wheat it was 27% less in each instance. Similar conclusions would be reached from either method except that Hope spring wheat responded more unfavorably to hardening at the intermittent temperatures. It should be pointed out that, although the seedlings were all of the same age

TABLE 2.—*Influence of continuous and intermittent hardening temperatures on the ability of spring grains to resist cold.**

Variety	Percentage survival after indicated conditions during hardening†		Stage of seedling development after hardening			
	Continuous temperature 2°-4°C	Intermittent temperatures day, 20°C; night, 2°-4°C	No. of leaves		Plant height, cm	
			Continuous temp.	Intermittent temp.	Continuous temp.	Intermittent temp.
Oats						
Nebr. 21	41	14	3	4	21	32
Kanota	68	57	3	4	19	31
Average	55	36	3	4	20	32
Barley						
Trebi	64	54	3	5	21	33
Spartan	66	55	3	6	24	34
Average	65	55	3	6	23	34
Spring Wheat						
Ceres	69	59	3	4	24	36
Hope	71	44	3	5	26	37
Average	70	52	3	5	25	37
Summary						
All crops	63	48	3	5	23	34

*All seedlings grown uniformly in flats for 15 days at 20°, hardened as indicated for 9 days, and exposed for 8 hours to a temperature of —9°C. Average of 12 replications, each replication consisting of about 30 plants of each variety at each hardening condition.

†The standard error of any varietal mean was 6.8 and 5.8 for the constant and intermittent temperatures, respectively.

and stage of development before they were placed in the hardening chamber, the seedlings subjected to intermittent hardening made some growth in the day time during the hardening period. Thus, at the time of freezing, although the seedlings in both groups were the same age, they were not in the same stage of development.

As has previously been mentioned, seedlings that have reached or passed the four-leaf stage are somewhat more resistant to cold than plants in the two- or three-leaf stage. This fact should be taken into consideration when the rather small differences between the percentage of survivors under the two conditions are compared.

The results suggest that spring grains may be hardened-off by either continuous or intermittent low temperatures.

COMPARATIVE HARDINESS OF OATS, BARLEY, AND SPRING WHEAT

Having established a satisfactory procedure for comparative cold resistance tests, the following experiment was undertaken. Nine replications of five representative varieties of each of the three spring grains and two varieties of winter wheat were sown in flats. A common check, Nebr. 21 oats, was placed in alternate rows in each flat. The seedlings were grown in a warm greenhouse for a 14-day period. They were then transferred to the hardening chamber and held for 7 days at a temperature of 2° to 4° C. Owing to the large number of flats, four separate exposures to the freezing temperatures were necessary. The exposure was for 8 hours at an average temperature of −10° C. After freezing, the flats were removed to a warm greenhouse and 2 weeks later a recovery count was made. The survivals listed in Table 3 are expressed as ratios to the Nebr. 21 oats.

TABLE 3.—*Comparative cold resistance of spring small grains.**

Variety	Survival ratio to Nebr. 21 oats†
Oats	
Nebr. 21	100‡
Iogold	109
Gopher	110
Kanota	**153**
Burt C. I. 293	**203**
Average	135
Barley	
Trebi	131
Spartan	**136**
Flynn	**144**
Glabron	**152**
Minn. 184	**200**
Average	153
Spring Wheat	
Java	138
Marquis	156
Garnet	**162**
Ceres	**170**
Arnautka	**180**
Average	161
Winter Wheat	
Blackhull	**295**
Nebr. 60	**405**
Average	350

*Based on a study of nine replications for each variety of about 30 plants per row. Plants grown for 14 days in flats at 20°, hardened for 7 days at 2° to 4°, and exposed for 8 hours to a temperature of —10°C.

†As determined by Student's paired method, all bold face survival ratios were significant, with odds greater than 25:1.

‡The average survival of the 144 replications of the Nebr. 21 oats grown as a control was 39%.

Comparing the mean results for the four different crops, the order of cold endurance was winter wheat, spring wheat, barley, and oats.

The oats varieties fell distinctly into hardy and relatively unhardy groups; the former being represented by Kanota and Burt. Iogold and Gopher were slightly more hardy than Nebr. 21 oats.

Minn. 184 was the outstanding cold resistant barley, followed by Glabron and Flynn. Trebi and Spartan were the least hardy.

Arnautka, a durum wheat, proved to be the most hardy spring wheat, while Java was the least hardy. It is rather striking that the other three varieties, two originating in Canada and one in North Dakota, exhibited less hardiness than the Burt oats or Minn. 184 barley. These most hardy spring varieties were, however, far less cold enduring than the relatively unhardy variety of winter wheat, Blackhull. Thus, while the spring wheats as a group are apparently more hardy than barley or oats, certain varieties of barley and oats are more cold resistant than any of the spring wheats so far tested. Such information may have value in planning the order of crop planting in early spring.

RELATION OF TEMPERATURE TO SEED GERMINATION OF OATS, BARLEY, AND SPRING WHEAT

It was thought important to determine whether these three spring small grains, or varieties within them, differ with respect to their germinative ability at various temperatures. Accordingly, 100 seeds of each of the 15 varieties tested for hardiness were incubated on moistened blotters at each of six temperatures, namely, 5°, 10°, 15°, 20°, 25°, and 30°C. The germination percentages were determined every other day for 2 weeks. There proved to be no significant differences among the varieties with respect to germinative response at any one temperature, except that the spring wheat germinated about 2 days earlier than oats or barley at the lowest temperature. While it required 8 days for complete germination of the oats and barley at 5°, the interval rather gradually reduced to 2 days for all crops at 20°C or above.

SUMMARY

Seedling plants of oats, barley, and spring wheat proved more cold resistant when just emerging from the soil or in the one-leaf stage than in the two- or three-leaf stages. It is considered that the seedlings manifest the least cold endurance when the food reserves of the endosperm become exhausted. The data suggest that varietal differences as to hardiness may best be distinguished at this more susceptible stage of development.

A greater degree of cold endurance resulted from exposure to a continuous than to an intermittent hardening temperature.

In their order of cold endurance in the hardened seedling condition, the spring grains may be ranked as spring wheat, barley, and oats. Varieties within any one of these crops differ materially in their cold endurance.

Equally good germination was obtained from these various spring small grains at low, medium, and high temperatures. Spring wheat germinates somewhat quicker than oats and barley at a low temperature.

LITERATURE CITED

1. ANDERSON, A., AND KIESSELBACH, T. A. Studies on the technic of control hardiness tests with winter wheat. Jour. Amer. Soc. Agron., 26: 44-50. 1934.

2. MARTIN, J. F. The cold resistance of Pacific Coast spring wheats at various stages of growth as determined by artificial refrigeration. Jour. Amer. Soc. Agron., 24: 871–880. 1932.
3. PELTIER, G. L. Control equipment for the study of hardiness in crop plants. Jour. Agr. Res., 43 : 177–182. 1931.
4. ———— and TYSDAL, H. M. The relative susceptibility of alfalfa to wilt and cold. Nebr. Agr. Exp. Sta. Res. Bul. 53. 1930.
5. ———— and TYSDAL, H. M. A method for the determination of comparative hardiness in seedling alfalfas by controlled hardening and artificial freezing. Jour. Agr. Res., 44 : 429–444. 1932.
6. SUNESON, C. A., and PELTIER, G. L. Cold resistance adjustments of field-hardened winter wheats as determined by artificial freezing. Jour. Amer. Soc. Agron., 26 : 50–58. 1934.
7. TYSDAL, H. M. Influence of light, moisture, and soil moisture on the hardening process in alfalfa. Jour. Agr. Res., 46 : 483–515. 1933.

EFFECT OF STAGE OF SEEDLING DEVELOPMENT UPON THE COLD RESISTANCE OF WINTER WHEATS[1]

COIT A. SUNESON AND GEORGE L. PELTIER[2]

The relative cold resistance of winter wheat seedlings of various ages, especially in regard to varietal relationships, has been determined only in a few instances. Experiments were therefore conducted in which the comparative cold resistance of different age groups and varieties within these groups was determined when grown in the greenhouse and hardened in various ways.

In this study five varieties, *viz.*, Blackhull, Kanred, Minturki, Nebr. 60, and Kawvale, were used, the primary purpose being to determine whether their relative cold resistance in the seedling stage depends in any way on the stage of development of the plant, the temperature of germination and growth, or conditions of hardening.

METHODS

The technic employed has been essentially the same as that previously reported (6).[3] Briefly, the method consisted of starting plants in flats in a warm greenhouse, hardening them previous to a 24-hour exposure to freezing temperature, and finally determining the survival by actual counts, after a 2-weeks recovery period in the greenhouse. The plants were hardened and frozen through the use of the control equipment described by Peltier (2).

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[1] Based on cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Departments of Agronomy and Plant Pathology, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Journal series paper No. 146 of the Nebraska Agricultural Experiment Station. Received for publication February 9, 1934.

[2] Junior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; and Plant Pathologist, Nebraska Agricultural Experiment Station, respectively.

[3] Numbers in parenthesis refer to "Literature Cited," p. 692.

RESULTS

EFFECT OF DURATION AND INTENSITY OF HARDENING ON COLD RESISTANCE OF WINTER WHEAT SEEDLINGS

Data pertaining to the comparative efficiency of hardening at a constant low temperature and with an alternating high and low temperature for various periods with three varieties of wheat are given in Table 1. These plants were germinated and grown at 68° F for 2 days before hardening. An average of 18 plants of each variety in each of six replications were given constant temperature hardening, and a like number of each variety in 12 replications were hardened under alternate temperatures. The two groups were then simultaneously frozen by exposure for 24 hours at 12° F.

Under conditions of constant hardening (29° to 35°F) plants increased in cold resistance up to 3 weeks. Additional hardening exposure up to 4 weeks added nothing to the capacity of the plants to endure a given low temperature. A similar result was reported by Peltier and Tysdal (3) for alfalfa, showing an interesting parallelism in the rate of hardening of the two crops under similar conditions. Under constant hardening conditions, irrespective of the duration, growth of the plants was almost completely arrested, but the color deepened and the decumbent stature increased somewhat.

Alternate hardening temperatures, in which the daytime mean averaged near 60° and the night about 40° F, influenced the actual cold tolerance for the several durations less than the constant temperature described above, as shown by the lower survivals. The general agreement, however, in relative varietal relationships and in efficiency of the several hardening durations suggests parallelism and the possibility of a rather wide latitude in hardening technic insofar as temperatures employed and actual degree of cold resistance acquired are concerned.

TABLE 1.—*Comparative survivals of seedlings of three varieties of winter wheat hardened at different temperatures and for different periods.*

Variety	C. I. No.*	Percentage survival after indicated hardening durations							
		At a constant temperature (29° to 35°F)				At alternate temperatures (range: day 65°, night 32°F)			
		28 days	21 days	14 days	7 days	28 days	21 days	14 days	7 days
Blackhull..	6251	72	72	64	12	21	43	12	0
Kanred....	5146	99	96	91	25	44	61	42	2
Minturki...	6155	94	95	87	22	43	64	37	3
Mean...	——	88	88	81	20	36	56	30	2

*Denotes accession number, Division of Cereal Crops and Diseases.

Three contrasted varieties were compared in these studies. No significant changes in their relative hardiness occurred as a result of differential response to duration or intensity of hardening prior to freezing. Kanred was consistently equal to or slightly more cold resistant than Minturki, while Blackhull was least hardy in all comparisons.

EFFECT OF AGE, STAGE OF DEVELOPMENT, AND METHOD OF HARDENING ON COLD RESISTANCE OF WINTER WHEAT SEEDLINGS

In these experiments three varieties at four stages of development, reckoned from date of emergence, were subjected to two types of hardening for a 7-day period and subsequently exposed to temperatures of 14° F for 24 hours. Six replications of each variety averaging 18 plants each were compared. The percentage of survivals are shown in Table 2, together with the results of a supplementary experiment involving only two age groups.

TABLE 2.—*Comparative survival of seedlings of three greenhouse-grown varieties of winter wheat differing in age, stage of development, and method of hardening.*

Variety	C. I. No.	Percentage survival after indicated age previous to 7-day hardening							
		At a constant temperature (33° to 39°F)				At an alternate temperature (range: day 70°, night 36°F)			
		25 days	18 days	11 days	4 days	25 days	18 days	11 days	4 days
		Experiment 1a (December, 1931)							
Blackhull..	6251	36	42	10	84	3	0	2	15
Kanred....	5146	50	46	11	98	6	0	11	22
Minturki...	6155	51	55	23	100	7	0	5	21
Mean...	——	46	48	15	94	5	0	6	19
		Experiment 1b (February, 1932)							
Blackhull..	6251	—	—	48	97	-	—	6	1
Kanred....	5146	—	—	90	99	-	—	9	17
Minturki...	6155	—	—	96	100	-	—	5	8
Mean...	——	—	—	78	99	-	—	7	9

The youngest plants appear to be the most cold resistant, regardless of the type of hardening, thereby confirming Klages' (1) early work with non-hardened plants. The low survivals obtained with plants emerged 11 days before hardening and in the 3- or 4-leaf stage when frozen have not previously been recognized. It is suggested that this may coincide with endosperm exhaustion, and that limited growth during hardening, as occurred under alternate temperature hardening, tends to delay this exhaustion. Pope (4) has shown a lag in the growth curve of barley following endosperm exhaustion just before tillering, and we have observed seedlings at a similar age and stage of development in which the dry weight of the seed was reduced to less than 10% of its original weight.

The data also suggest that despite close duplications of manner or intensity of hardening, thru temperature control, reversed varietal relationships may occur in sequential experiments. Thus, the hardiness relationship of Kanred and Minturki under constant temperature hardening, as shown in Table 2, is quite opposite to the relationship shown under alternate temperature hardening, while in the very similar experiment reported in Table 1 reversed relations between these two varieties were not obtained in comparing the two types of hardening. The comparison is at least suggestive of the importance in hardening of factors other than temperature in adjusting varietal relationships.

EFFECT OF GROWING TEMPERATURES AND STAGE OF DEVELOPMENT ON SURVIVAL OF VARIETIES

Having determined that plant age and stage of development prior to hardening were conducive to different degrees of actual cold resistance under the technic employed in testing greenhouse-grown seedlings, the investigations were expanded to compare more thoroughly varietal relationships within the age range previously studied. Two contrasting growing temperatures for the four age groups were also studied. All plants involved were simultaneously hardened by 10-day exposure to constant temperatures of 32° to 39° F. Seed comparable as to plumpness and origin was used. Results with four varieties are listed in Table 3. In general, the results confirm those previously reported herein. The youngest seedlings exhibited the greatest and the seedlings in the apparent transition stage between endosperm dependence and tillering the least tolerance to cold. It was also consistently noted that seedlings emerged only 1 or 2 days were materially more cold tolerant than those 2 or 3 days older.

In comparing the two growing temperatures the youngest seedlings grown at 60° prior to hardening showed greater resistance to cold than those grown at 77° F, but in the three more advanced age groups the seedlings grown at the higher temperatures before hardening were subsequently found to be more cold resistant. In comparing the survival of the four varieties in these three age groups the 77° prehardening temperature was superior to the 60° F temperature in 54 out of 80 comparisons. In the case of the youngest plants it would seem that the low temperatures during growth may have effected the retardation of both growth and endosperm depletion.

Relative varietal relationships appeared to vary with plant age, irrespective of growing temperatures prior to hardening. This was especially true in the changed relative ratings of Minturki to Kawvale and Nebraska 60 before and after 12 to 14 days of growth; and in the extreme lack of cold resistance in the youngest Kawvale plants. Since the age groups shown are themselves quite arbitrary, and the number of comparisons frequently inadequate to establish significance by the generally conservative point binomial formula (5), it has seemed legitimate to combine sequential group averages and associated paired distributions in arriving at these conclusions. Information at hand particularly condones combinations to include 1- to 12-day and 14- to 26-day age groups. Such combinations are not shown in Table 3 but can readily be made therefrom.

TABLE 3.—*Comparative cold resistance of seedlings of four varieties of winter wheat each in four successive stages of development and grown at two different temperatures, as determined by artificial freezing.*

Age group in days from emergence to hardening	Germination and growth at °F	Average survival, %					Intervarietal replicate pairings					
							Nebr. 60*			Minturki*		Kawvale*
		Blackhull	Minturki	Nebr. 60	Kawvale	Ave.	Blackhull	Kawvale	Minturki	Blackhull	Kawvale	Black hull
1 to 5	60°	91	95	93	88	92	5–3	5–3	3–4	5–3	5–2	2–4
1 to 5	77°	74	82	83	69	77	5–2	7–1	4–4	5–2	7–0	1–6
7 to 12	60°	25	49	39	37	38	5–3	4–4	3–5	7–1	6–2	7–1
7 to 12	77°	37	63	64	58	56	8–0	6–2	4–4	7–1	6–2	8–0
14 to 19	60°	33	36	52	43	41	6–2	7–1	7–1	4–3	2–6	7–1
14 to 19	77°	22	50	48	58	44	8–0	3–5	4–4	7–1	2–6	7–1
21 to 26	60°	34	53	76	60	56	4–0	3–1	3–1	4–0	1–3	4–0
21 to 26	77°	51	65	78	63	64	3–0	2–2	3–0	3–0	1–2	3–0

*Base varieties in relation to all others with number of times superior and inferior shown successively, with ties omitted. Significant differences assumed for the following distributions (Salmon's point binomial formula): Any single age or temperature comparison, 4 or more to 0; or 7 or more to 1. In combination comparisons of two sequential age groups or growing temperatures, 10 or more to 2; or 12 or more to 4.

The evidence of differential varietal relationship, due to a difference in growing temperatures prior to hardening, is somewhat less conclusive. In contrasting the survival of both tillered and non-tillered plants, i. e., 14- to 26-day vs. 1- to 12-day groups, of Kawvale and Nebraska 60 grown at 60° and 77°F before hardening, we have, however, a strong indication of reversal.

SUMMARY

Winter wheat seedlings in four 1-week interval stages of development from emergence to past tillering were compared for cold tolerance. Very young seedlings, presumably still dependent upon the endosperm to a considerable degree were found to excel all other more advanced stage of development groups in cold tolerance, whereas seedlings emerged from 7 to 12 days prior to controlled hardening and freezing, and probably on the verge of endosperm independence, were least cold tolerant.

Hardening by exposure to a constant or an alternate (warm day and cold night) temperature near freezing revealed that actual cold resistance increased materially from exposure up to three weeks and none thereafter up to four weeks. The ranking of varieties was not affected by the duration of the hardening periods employed.

Differences in varietal cold resistance relationships are indicated from (a) dissimilar growing temperatures or (b) dissimilar ages and stages of plant development at the time of initiating uniform hardening and freezing. These results, together with the seasonal effects reported in a previous paper (6), all point to the great importance of factors other than exposure to low temperatures and resultant high specific cold tolerance as determinators of the relative resistance of winter wheat varieties to cold.

LITERATURE CITED

1. KLAGES, K. H. W. Relation of soil moisture to resistance of wheat seedlings to low temperatures. Jour. Amer. Soc. Agron., 18 : 184–193. 1926.
2. PELTIER, GEORGE L. Control equipment for the study of hardiness in crop plants. Jour. Agr. Res., 43 : 177–182. 1931.
3. ————, and TYSDAL, H. M. A method for the determination of comparative hardiness in seedling alfalfas by controlled hardening and artificial freezing. Jour. Agr. Res., 44 : 429–444. 1932.
4. POPE, MERRITT N. The growth curve in barley. Jour. Agr. Res., 44 : 323–341. 1932.
5. SALMON, S. C. The point binomial formula for evaulating agronomic experiments. Jour. Amer. Soc. Agron., 22 : 77–81. 1930.
6. SUNESON, C. A., and PELTIER, GEORGE L. Cold resistance adjustments of field hardened winter wheats as determined by artificial freezing. Jour. Amer. Soc. Agron., 26 : 50–58. 1934.

EFFECT ON THE GROWTH OF OATS OF COPPER SPRAYS USED FOR THE CONTROL OF MUSTARD[1]

O. BUTLER and RUSSELL BISSEY[2]

Rommetin,[3] reflecting the general consensus of opinion, tells us that however scorched and browned oat foliage may appear after a copper spray has been applied for the control of mustard, the injury caused is transient and in no way affects the future development of the plant. Oats in sprayed fields no doubt apparently recuperate promptly following the application of a copper herbicide, but in reality do they recover as quickly and as completely as currently supposed?

The authors have made a few experiments with oats which show that the injury produced by a copper herbicide persists for a longer period than is commonly believed. The oats, both free from and admixed with mustard, were grown in pots in fertile soil the water content of which was held at 70% of saturation in the usual way. The herbicide used was in most instances copper nitrate, though in one case copper sulfate was also employed.

RESULTS

Experiment 1.—The pots used were 22.7 cm high and 27.0 cm in diameter and held 6,000 grams of air-dry soil. Three grams of oats were sown per pot and 1 gram of mustard was added to those containing both oats and mustard.

Nineteen days after date of planting the oats were approximately 6 inches tall and the mustard plants had developed 3 or 4 leaves. One-half the pots of oats and all the pots of oats and mustard were now sprayed with a 3% solution of copper nitrate. Within 24 hours the mustard plants were all dead and the tips of the leaves of the sprayed oats were scorched. However, the injury produced soon became inconspicuous and without previous knowledge one would have had diffculty in distinguishing the sprayed from the non-sprayed oats. Fifty-five days after planting, when the oats were heading, measurements were taken of the height of the plants and the crop was harvested. The data obtained are presented in Table 1. In the case of the sprayed oat plants it will be noticed that they were 8.1% shorter than the non-sprayed plants and weighed 18% less. The oats in the

TABLE 1.—*Effect of spraying oats and oats and mustard with 3% copper nitrate on growth and yield in dry matter of the cereal.*

Method of treatment	Mean height, cm	Mean dry weight, grams
Oats not sprayed	66.6	36.6
Oats sprayed	61.2	30.0
Oats and mustard sprayed	55.2	23.2

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[1] Contribution from the Department of Botany, New Hampshire Agricultural Experiment Station, Durham, N. H. Received for publication February 12, 1934.

[2] Professor of Botany and Research assistant, respectively.

[3] ROMMENTIN, H. Destruction des sanves. Jour. Agr. Prat., I : 754–755. 1903.

pots that had been planted to oats and mustard were even more severely stunted than the sprayed oats and yielded 36.6% less than the non-sprayed oats.

Experiment 2.—A number of pots 11.5 cm in diameter, 16.0 cm high, and containing 900 grams of air-dry soil were divided into two series, one series planted with oats and the other with oats and mustard. After the plants had grown 19 days the pots were divided into lots and treated in the following manner:

A—oats, not sprayed.

B—oats and mustard, not sprayed.

C—oats and mustard, mustard clipped off.

D—oats and mustard, sprayed with 10% nitrate of copper and dried quickly.

D′—oats and mustard, sprayed with 10% nitrate of copper and dried slowly.

E E′—oats and mustard, sprayed with 5% copper nitrate and handled in the same way as D D′.

F F′—oats and mustard, sprayed with 2½% copper nitrate and handled in the same way as D D′.

G G′—oats and mustard, sprayed with 1¼% copper nitrate and handled in the same way as D D′.

H H′—oats and mustard, sprayed with 0.6% copper nitrate and handled in the same way as D D′.

The plants in the quick-drying series were always dry within 2 hours after the spray had been applied, while the plants in the slow-drying series were kept wet for 6 hours and then allowed to dry spontaneously.

In the series sprayed with 10% copper nitrate the oats were severely injured and the mustard killed; the 5, 2.5, and 1.25% solutions killed the mustard and burned the tips of the oat leaves; and the 0.6% copper nitrate solution caused no injury to the oats and did not kill all the mustard.

As in the case of experiment 1, a few days after the spray was applied the oats showed signs of recovery and at the time the experiment was concluded it was difficult to detect any differences as between the sprayed and unsprayed oats. Again, however, appearances proved deceptive.

A study of the data presented in Table 2 shows that the presence of mustard in the oats reduced the yield of the cereal 20.9%, but that when the weed was clipped out instead of being killed with a spray the reduction in yield was 5.3%.

Looked at in another way the increased yield obtained by clipping out the mustard instead of allowing it to remain was 19.7% which is substantially the same increase as was obtained when the yield of oats grown alone is compared with that of oats grown in the presence of mustard. It will also be noticed that slow drying was not consistently more injurious than quick drying and this is in agreement with the observations made following the application of the herbicide. The data obtained also show that the copper nitrate depressed the yield of the oats very nearly proportionally to the concentration.. At one extreme the loss in yield is negligible, at the other it reaches the

TABLE 2.—*Effect of concentration of a copper nitrate spray on the yield of oats.*

Series	Method of treatment	Dry weight, grams
A....	Oats, not sprayed	1.960
B....	Oats and mustard, not sprayed	1.550
C....	Oats and mustard, mustard clipped off	1.856
D....	Oats and mustard, sprayed	1.130
D'....	Oats and mustard, sprayed	1.260
E....	Oats and mustard, sprayed	1.575
E'....	Oats and mustard, sprayed	1.420
F....	Oats and mustard, sprayed	1.785
F'....	Oats and mustard, sprayed	1.775
G....	Oats and mustard, sprayed	1.610
G'....	Oats and mustard, sprayed	1.480
H....	Oats and mustard, sprayed	1.795
H'....	Oats and mustard, sprayed	1.835

substantial figure of 35%. The 0.6% copper nitrate, it will be remembered, did not injure the oats and did not kill all the mustard. Nevertheless, the cereal yielded substantially as well as when the mustard was clipped out, whence it would appear that a small percentage of mustard is less injurious to oats than is the use of copper nitrate of a strength sufficient to obtain a perfect kill.

Experiment 3.—Ten pots similar in size to those previously used were planted with oats and then with oats and mustard. Thirteen days after planting the oats in all the pots were thinned to 17 plants per pot. Twenty-one days after planting the mustard had developed three to four leaves and all the pots were divided into series treated as follows:

A—oats, not sprayed.
B—oats, sprayed with 1.25% copper nitrate.
C—oats and mustard, not sprayed.
D—oats and mustard, sprayed with 1.25% copper nitrate.

Forty-eight hours after the sprays were applied the mustard was dead and the oats showed slight injury, mostly scorching of the leaf apices. The cereal soon recovered from the effects of the spray, however, and after an interval sprayed and unsprayed plants were not readily distinguishable.

Thirty days after spraying the oats were harvested. A study of the data presented in Table 3 will show that when oats were grown alone the spray reduced the yield 19.2%, a figure in close agreement with that obtained in experiment 1. In the case of the sprayed pots containing oats and mustard the results obtained were less marked than in experiment 1. The loss in yield was 4.2% instead of 36.6%. It

TABLE 3.—*Effect of spraying with 1.25% solution of copper nitrate on yield of oats.*

Method of treatment	Dry weight, grams
A—oats, not sprayed..................................	4.779
B—oats, sprayed..	3.859
C—oats and mustard, not sprayed.....................	4.535
D—oats and mustard, sprayed.........................	4.575

will also be noted that when the mustard was allowed to grow the loss in yield was 5.1%; that is, the oats yielded practically as well when the mustard grew unchecked as when it was killed. These results do not agree with those obtained in experiment 2, but it should be observed that in the present instance the number of oat plants grown per pot was approximately 70% of the number grown in the former so that competition may be in large measure responsible for the differences in behavior.

Experiment 4.—Fifteen pots of the size used in the previous experiment were planted with oats and 15 with oats and mustard. Ten days after planting the oats were thinned to 17 plants per pot. Seventeen days after planting the mustard had developed three to four leaves and the pots were sorted into seven series treated as follows:

A—oats, not sprayed.
B—oats, sprayed with 2.5% copper sulfate.
C—oats, sprayed with 2.5% copper nitrate.
D—oats and mustard, not sprayed.
E—oats and mustard, mustard clipped out.
F—oats and mustard, sprayed with 2.5% copper sulfate.
G—oats and mustard, sprayed with 2.5% copper nitrate.

Forty-eight hours after spraying the mustard in the pots sprayed with copper nitrate was dead and the oats showed the usual injury with the outermost leaves scorched severely and the tips of other leaves burned. In the pots sprayed with copper sulfate the mustard was either dead or severely injured, but the oats only showed signs of slight injury, i.e., a few leaves with scorched tips. Within a few days the differences between the oats sprayed with copper nitrate and copper sulfate, which were at first obvious, became slight and recognizable mainly by the dry remains of the dead outer leaves adhering to the plants sprayed with the former material. Twenty-five days after spraying the experiment was closed.

The data presented in Table 4 show that when the mustard was allowed to grow the oats yielded 15% less than the seeding free from mustard. The loss in yield when the mustard was clipped out was 4.5%, a figure of the same order of magnitude as that obtained in experiment 2. The loss in yield of the oats sprayed with copper sulfate and copper nitrate was, respectively 6.5% and 6.7%. In the pots seeded to oats and mustard the copper sulfate spray proved less injurious to the oats than the nitrate, the cultures sprayed with the latter yielding 3.4% less than those sprayed with the former.

TABLE 4.—*Effect on the yield of oats of copper nitrate and copper sulfate sprays.*

Method of treatment	Dry weight, grams.
A—oats, not sprayed	4.050
B—oats, sprayed with sulfate	3.786
C—oats, sprayed with nitrate	3.775
D—oats and mustard, not sprayed	3.440
E—oats and mustard, mustard clipped out	3.865
F—oats and mustard, sprayed with sulfate	3.503
G—oats ant mustard, sprayed with nitrate	3.382

SUMMARY

The experiments described show that oats are sensitive to a copper spray and that recovery, which has all the appearance of being rapid, is in reality slow and still far from complete at the time the cereal has passed the mid-point of its period of vegetation, and it may, therefore, be legitimately doubted that recovery is ever complete. The results obtained in experiment 2, however, indicate that the extent of the injury produced immediately following the application of a copper spray affects the degree of recovery.

When the strength of the spray used caused no injury the loss in yield was not materially greater than when the mustard was clipped out. It would seem, therefore, that when using a copper spray, and inferentially any herbicide, the strength used should be adjusted to give the weed control desired with the least possible injury to the cereal. Too much should not be taken for granted from the apparent rapid recovery of injured plants.

THE ANTHOCYANIN PLANT COLORS AND YIELD IN CORN[1]

R. A. BRINK[2]

Within the species *Zea Mays* several anthocyanin plant colors occur. All the important dent varieties and many of the sweet and pop corns grown in and adjacent to the corn belt of the United States, however, belong to a single color class, *viz.*, dilute sun red. It is an interesting question whether the presence of this particular pigment is purely fortuitous or whether the color was chosen because it was thought to confer some advantage on the plant. The early literature on corn is singularly devoid of reference to pigmentation other than that of the kernel, and it seems likely, therefore, that little notice was taken of the plant colors. The early corn breeders, doubtless, were interested largely in characteristics whose relation to yield in heterogeneous material is more or less obvious, and the anthocyanin colors are clearly not in this category. No evidence has been found, moreover, to indicate that at any later period in the history of corn improvement the possible physiological significance of the different anthocyanin plant colors has been considered.

It is the primary object of the present communication to show that the plant colors play a rôle in the development of certain qualities which it is the object of breeding to enhance, and that, in the further improvement of corn, anthocyanin colors other than dilute sun red may possibly be used to advantage.

In a series of experiments extending over more than a decade and noteworthy for the wide range of material embraced, the detail to which the observations were carried, and the extent to which the interpretation offered for the complex relations discovered is buttressed with proof, Emerson[3] has worked out the genetic basis of the principal plant colors and many of the subsidiary types found in corn. Emerson's fundamental work is not only the point of departure in any consideration of the physiological relations of the pigments, but also provides a sound basis for synthesizing to order stocks of the various color types as may be desired for comparative tests. The reader is referred to Emerson's monograph for descriptions of the color classes and the genetic relations between them.

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[1] Paper No. 166 from the Department of Genetics, Wisconsin Agricultural Experiment Station, Madison, Wis. Published with the approval of the Director. Received for publication January 24, 1934.

[2] Professor of Genetics. This work was completed while the author was on a research appointment made possible by the Wisconsin Alumni Research Foundation. The author wishes also to acknowledge the aid given in the experiments by H. R. Albrecht, Assistant in Genetics

The present study deals with the effects on yield of ears of substituting for the familiar dilute sun red pigmentation of the common varieties of corn three other colors, *viz.*, sun red, dilute purple, and purple. In the families in which the comparison was made three-quarters of the residual heredity was derived from selfed lines of corn bred from yellow dent varieties adapted to the region of Madison, Wisconsin, where the tests were carried out. The remaining quarter of the residual inheritance came from a genetic tester stock of medium size and relatively early maturity. As would be expected, therefore, the plants in the segregating families approximated the local dent corn in type, although somewhat inferior to it in size and uniformity.

GENETIC PROCEDURE

Seven different inbred strains of dent corn, dilute sun red (*A b pl*) in color, were crossed with a brown plant (*a B Pl*) genetic tester stock. The next season pollen from the resulting series of purple crossbreds (*Aa Bb Pl pl*) was applied to a vigorous F_1 dent corn hybrid (*A b pl*) whose parents were two very uniform and distinctly superior inbred lines. In the eleven families, each from a single backcrossed ear, which were grown out in 1933, plants of the four color classes, purple (*A B Pl*), dilute purple (*A b Pl*), sun red (*A B pl*), and dilute sun red (*A b pl*), were expected in approximately equal numbers.

ACCURACY OF CLASSIFICATION

In 6 of the 11 families (PC 8, 9, 10, 12, 14 and 16), the observed ratios conformed rather closely to the expected values and in one (PC13) the differences were not large. In each of the four other families (PC 6, 7, 11 and 15), however, there was a well-marked excess of dilute sun red individuals. The dilute purple class throughout the series tended to be low in numbers, although the deficiency was not large in any single progeny. The total frequencies were 925 purple, 750 dilute purple, 851 sun red, and 1,082 dilute sun red.

There are three possible explanations of the non-conformity of the observed distribution to expectation on the Mendelian basis which may be considered, namely, fluctuations of sampling, differential viability of the color types, and errors in classification. The deviations, in general, are too large to attribute to sampling alone. Nor is the author inclined to attribute any considerable part of them to differential elimination. In a preliminary test in 1932, three families of the same breeding, comprising 756 plants, were grown under more severe conditions of competition. The frequencies in the purple, sun red, and dilute sun red classes in this case were nearly the same. Only the dilute purple class was somewhat lower than would be expected as a result of random sampling. While differential elimination, therefore, may be a factor in the case of dilute purple, it seems unlikely that it accounts for the deviations in the other classes. There remains to be considered possible errors in classification.

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[3] EMERSON, R. A. The genetic relations of plant colors in maize. Cornell Univ. Agr. Exp. Sta. Mem. 39. 1921.

The plants were classified during the flowering period, the plat being gone over four times at intervals of 2 to 4 days. The dilute purple and the sun red plants were marked at this time, the other two classes being readily separated at maturity. At the flowering stage purple plants are much darker in color than any of the other classes and can be distinguished with certainty. At this time the dilute purples show comparatively little anthocyanin pigment and can be identified with equal assurance by their purple anthers. It is believed that very few mistakes were made in classifying these two groups. On the other hand, sun red and dilute sun reds are less readily separated under ordinary field conditions, particularly in some families. Emerson has called attention to the fact that environmental conditions, especially the moisture and nitrogen supply, may influence the amount of pigmentation and, doubtless, differences in the residual heredity also have an effect. In the present case each plant was scrutinized at least twice and placed in the sun red or dilute sun red class according as it showed more or less red color. It is the author's opinion that the excess of dilute sun red individuals in certain families is due to the fact that the amount of pigment developed in some sun red plants at the flowering stage in these progenies was little more than that in the more highly colored dilute sun reds in other progenies, and that the circumstance passed unnoticed at the time. Had a check been made at a somewhat later stage some of the mistakes made might have been rectified.

How large is the resulting error and how important is it? Assuming that the difference in the frequency of the sun red classes is due entirely to this cause and that the mistakes were in one direction only, the error amounts to about 6% of the plants in the two groups. Just how significant this is considered to be depends upon what assumptions are made as to the yield of the misclassified plants. If one computes the average dry weight of ears of the sun red and dilute sun red classes for the six families in which no disturbance in the ratio is evident, the difference between the means is reduced from .058 pound to .040 pound. Relatively, this is a rather large change. But, in like manner, the mean difference between dilute purple and purple is reduced from .129 pound to .110 pound, and there are no grounds for suspecting the classification of these plants. Therefore, while the irregularities in the ratio introduces an element of uncertainty in the sun red and dilute sun red results, there are no grounds for thinking that they have changed the order in which the color classes stand in mean yield, although they may have altered the absolute values somewhat.

FIELD TECHNIC

The segregating families were grown out in rows 42 inches apart, with the seed spaced at approximately 10 inches. Several of the ears contained about 20% of kernels with mottled purple aleurone. These colored seeds were included with the rest. The seeds giving rise to plants of the four respective color classes were necessarily distributed in the rows at random, an important fact from the standpoint of reducing to a minimum the effects of soil heterogeneity on the mean yields. As mentioned above, the plants were classified for color at the flowering stage. The number of individuals of each color class in each family was taken just prior to picking. Harvesting was done when the plants had reached a well-advanced stage of maturity. With comparatively few exceptions, in fact, the grain was firm. The field weights were taken immediately after picking. The drying was done in an efficient forced draft bin-type dryer. The weights upon which the comparisons made below are based were taken after the ears had stood in a cool, dry room for about 10 days after removal from the dryer.

With one exception, PC 7, where the number of plants dropped to 175, the families were rather uniform in size. The average number of individuals per class per family was 82.

MOISTURE CONTENT

The average percentage losses in moisture on drying for the four color classes are as follows: Purple, 47.9; dilute purple, 48.2; sun red, 49.5; dilute sun red, 51.7. These values may appear high for well-matured corn harvested during comparatively dry, warm weather. Other corn of similar maturity picked at the same time at Madison contained only about 30% moisture. The probable explanation for the difference is that it was necessary, during the latter part of August, to cover the ears in the plant color experiment with paper bags to protect them from the depredations of red-winged blackbirds. The bags remained in place until the ears were picked and doubtless retarded appreciably the evaporation of moisture. This circumstance of course, limits the value of the data on moisture content. So far as may be inferred from the figures, however, there is probably no significant difference in loss in weight on drying between the different color classes.

EXPERIMENTAL RESULTS

In expressing the results the dry weights of the ears from each color class in each family were divided by the respective numbers of plants, both fruitful and barren, in the several groups. The average dry weights of ears in pounds per plant are given in Table 1. The probable errors of the means of the color classes were computed by Fisher's variance method.[4] Consequently, the estimate of the error of the experiment is based on all 44 entries, allowance being made for the variance due to the differences in the means of the color classes and in the means of the families.

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[4] GOULDEN, C. H. Statistical methods in agronomic research. Can. Seed Growers' Assoc. Plant Breeders' Ser., Pub. No. 2. 1929

TABLE 1.—*Average air-dry weight of ears in pounds per plant of the four color classes of corn.*

Progeny No.	Color type			
	Purple	Dilute purple	Sun red	Dilute sun red
PC 6	.598	.770	.646	.546
PC 7	.455	.700	.731	.612
PC 8	.388	.548	.525	.510
PC 9	.413	.372	.554	.505
PC 10	.374	.500	.467	.462
PC 11	.452	.526	.571	.485
PC 12	.411	.615	.562	.518
PC 13	.429	.647	.543	.547
PC 14	.405	.454	.519	.470
PC 15	.418	.464	.557	.462
PC 16	.416	.577	.585	.508
Average....	.433 ± .0085	.561 ± .0110	.569 ± .0111	.511 ± .0100

The dilute sun red class may be taken as the standard since it is the color type represented in most commercial varieties of corn. The purple group is clearly inferior. The odds against the difference (.079 ± .0131 lbs.) between dilute sun red and this class being due to chance alone are about 19,000 to 1. The difference in average weight of ears between the dilute purple and sun red plants is very small and not significant statistically. Both these types, however, yielded more than dilute sun red, and the differences are large enough to render it rather unlikely that they are due to chance. The excess in yield of the dilute purple over dilute sun red is .050 ± .0149 pound, or nearly 10%, and would be expected to result from sampling alone only once in about 38 trials. The corresponding value in the case of sun red is .058 ± .0150 pound (about 11%), and the odds against this difference being the result of chance are about 100 to 1. In 10 of the 11 families sun red outyielded dilute sun red and in 9 of the families dilute purple exceeded the standard class. Purple, on the other hand, was inferior to dilute sun red in 10 of the 11 cases. This relatively consistent behavior lends support to the view that there are inherent differences in yielding capacity between these three color types and dilute sun red, purple being less and dilute purple and sun red more productive.

ARE THE DIFFERENCES DUE TO THE COLOR GENES?

The question may well be raised whether the differences shown are due to the color genes themselves or to some factors linked with them. The segregating families were bred in such a way as to equalize on the average, the residual heredity between the different color classes except for the chromosome segments in which the *B b* and *Pl pl* pairs lie. May it not be that unidentified genes in these regions are responsible for the observed effects? Such an explanation appears improbable for the following reasons. When either *B* or *Pl* is substituted for its allelomorph in dilute sun red, giving sun red and dilute purple, respectively, the yield is increased. But when both are substituted simultaneously, giving purple plants, the average weight of ears declines. This behavior cannot be accounted for on the hypothesis that genes linked with the color factors are the effective agents unless, indeed, it is assumed that they interact in a way similar to color factors themselves. Such an interaction is possible, of course, but not very probable. Moreover, since the *B* and *Pl* genes were introduced from a relatively inferior stock, it would be expected that the chromosome segments which bear them would carry genes less advantageous to growth, on the average, than those associated with their respective allelomorphs, *b* and *pl*.

RESULTS OF AN EARLIER TRIAL

In the summer of 1932 a preliminary test of the effect of the anthocyanin plant colors on yield of ears was made. Three families of the same breeding as the material grown in 1933 and discussed above were studied. The main difference between the two trials, aside from the numbers involved, was that in 1932 the plants became overcrowded in the rows as the result of warm, wet weather, which caused an unusually rank early growth, followed by very dry, hot weather. This combination of circumstances made the competitive conditions from midseason onwards very severe and caused considerable barrenness. Except in the dilute purple class, which was rather low, the numbers of plants in the four color classes closely approximated the Mendelian expectation. The average dry weight of ears per plant based on all the individuals, fruitful and barren, and taking the dilute sun red class as 100.0, were as follows: Purple, 84.6; dilute purple, 105.7; sun red, 105.6. In two of the three families sun red and dilute purple were superior to dilute sun red. In the third progeny dilute sun red gave the highest yield. Purple was lowest in all three cases.

The percentages of barren plants in the 1932 trial were as follows: Purple, 35.4; dilute purple, 29.5; sun red, 28.7; and dilute sun red, 30.5.

DISCUSSION

Insofar as one may judge from the results of these two experiments, the anthocyanin plant colors in corn appear to have an appreciable effect on yield of ears. There is little doubt that the intensely pigmented purple type is definitely at a disadvantage as compared with the three other classes. Sun red and dilute purple, on the other hand, are at least equal to the standard dilute sun red and possibly enough better to justify their consideration in corn breeding. No attempt will be made here to account for the apparent differences in physiological effect of the color genes.

It will be appreciated by the reader that while the 1933 experiment was carried out on lines which proved fairly adequate for the purpose in mind, the amount of information it affords is limited, after all, from the standpoint of the corn breeder. The effects of but one season in one locality were sampled, and the differences found are a reflection of the action under these particular conditions of the anthocyanin color genes on one fairly homogeneous background of residual heredity. It would be contrary to all experience in field experiments if the results obtained in this one trial should prove representative of those from other tests where the soil, the climate, and the strain were different. The findings, however, suggest that certain of the anthocyanin plant colors not now widely represented in corn may have an economic value which has not been suspected hitherto. Definite proof of the significance of these pigments for yield can only be had, however, from wider trials in which the numerous important variables affecting productivity may be said to have been fairly sampled.

SUMMARY

Following a preliminary test in 1932, a trial was made in 1933 of the relative yielding capacity of corn of four different anthocyanin plant colors, namely, dilute sun red, which characterizes most of the present varieties of economic importance, sun red, dilute purple, and purple. The stocks were bred so that all four color classes occurred with approximately equal numbers in each of the 11 families from which the data were taken.

Except for the genes closely linked with the color factors themselves, it may be supposed that the residual inheritance, on the average, was the same for each color class. Three-quarters of the residual inheritance came from selfed strains derived from dent corn varieties adapted to the region of Madison, Wisconsin.

The average dry weight of ears in pounds per plant for the four classes were as follows: Purple, .433 ± .0085; dilute purple, .561 ± .0110; sun red, .569 ± .0111; and dilute sun red, .511 ± .0100. Taking the dilute sun red class as the standard, the purple type is clearly inferior. Dilute purple and sun red, on the other hand, showed increases in yield over the standard class which may be adjudged statistically significant, the differences being 3.35 and 3.85 times their respective probable errors.

Final conclusions regarding the significance of the anthocyanin plant colors in corn improvement, however, must await the results of trials representative of a wider range, not only of soil and climatic conditions, but also of back-grounds of residual heredity.

YIELD COMPARISONS OF HYBRID AND OPEN-POLLINATED VARIETIES OF SWEET CORN[1]

E. S. HABER[2]

The market value of canned sweet corn is determined primarily by its quality. The variety factor, together with climatic considerations, has been regarded of great importance in determining the quality of the canned product. Improvement in the quality of the raw product should result in better canned corn. The use of hybrid sweet corn seed should produce a better quality raw product if the right hybrids are used.

The breeding of sweet corn as reported in the literature bearing on the subject has been confined largely to the genetics of the subject. Very little work has been reported on the improvement of strains and the production of new varieties. Earlier work, previous to the last 5 or 10 years, has been confined largely to the development of new varieties by hybridization of standard varieties or through improvement by selection within existing strains. Numerous reports appear in the literature dealing with production and results secured from inbreeding field corn, but very little has been reported on results which can be expected from such a project when applied to sweet corn. This report, therefore, will be found to deal with the comparison of some hybrid sweet corn strains developed at the Iowa Agricultural Experiment Station and varieties in use by canners in the corn belt region.

REVIEW OF LITERATURE

No attempt will be made to review the literature with regard to the genetics of corn breeding, nor to review the extensive studies that have been reported on the relation between various characters and yield in open-pollinated field corn or sweet corn.

Hayes (3)[3] found in 1929 that the first five crosses of first generation hybrids between lines of Golden Bantam sweet corn selfed for 6 to 7 years yielded from 22 to 69 % more corn than open-pollinated Golden Bantam. Lindstrom (7) crossed commercial varieties of dent corn and sweet corn with inbred sires which produced significantly increased yields of grain. Prepotency of the inbred sire for ear type, disease resistance, lodging, and uniformity was established.

In the selection of inbreds for crossing, a knowledge of the ability of the lines to use available nutrient materials is desirable. Smith (8) discovered that some inbred lines showed distinct differences when grown with a limited phosphorus supply. Evidence of differential response to a low nitrogen supply was less pronounced. No definite relationship was found between phosphate efficiency and percentage composition of phosphorus in the inbred lines. He considered the dominance of ability to absorb nutrients more rapidly to be due to favorable growth factors concerned with hybrid vigor.

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[1] Contribution from the Department of Vegetable Crops, Iowa State College, Ames, Iowa. Journal Paper No. J 155 of the Iowa Agricultural Experiment Station, Project 293. Received for publication February 21, 1934.

[2] Research Assistant Professor.

[3] Figures in parenthesis refer to "Literature Cited," p. 712.

PRESENTATION OF DATA

Inbreeding of sweet corn varieties was started by the Vegetable Crops Subsection of the Iowa Agricultural Experiment Station in 1926. Varieties and strains of corn which were chosen for inbreeding were those which were used by several canners in the state. Since the largest acreage of corn canned in Iowa is of the Evergreen variety, more strains of this were used than any other type. Several strains of Country Gentleman which were used by canners and appeared to be outstanding were included in the breeding program.

A number of golden lines which had been selfed 1 year by Dr. Lindstrom of the Genetics Department were also used. Most of these lines secured from him were the result of crossing sweet corn and field corn and selecting, for further inbreeding, the sweet segregates from such crosses. After four generations of inbreeding, lines were selected for crossing to determine the prepotency. Although Jones (6) found that lines selfed for 7 years showed appreciable heterozygosity, for all practical purposes the selection of prepotent lines can be determined to a considerable extent after four generations of selfing or perhaps after three generations of selfing. Lindstrom (7) reported on the prepotency of inbred-sires for ear type, lodging, yield, etc. in top-cross hybrids. Jenkins and Brunson (5) found they could eliminate 50% of their inbred lines by using the top-cross hybrids as a measure of the value of inbreds in hybrid combination. Practically all homozygous lines when combined with a variety will produce lines which are more uniform, but if the inbred does not have the ability to improve the yield it is usually safe to discard such a line. Of course, many selfed-lines were discarded before using them in variety-inbred crosses because of other undesirable characters. Practically all of the inbreds used in the various hybrids presented in the following tables were first tested in variety-inbred crosses.

In testing yields of hybrids and varieties, two rows of 10 hills each were planted in check rows 3½ feet apart each way. Five seeds were planted per hill and when the corn was 3 to 4 inches high the hills were thinned to three plants to insure an even stand as far as possible. All single crosses were replicated five times, while 3-way, double, and variety-inbred crosses, as well as varieties, were replicated eight to ten times. Each variety and hybrid was planted in randomized blocks. Evergreen, Country Gentleman, and Golden hybrids were randomized in blocks separately.

Yield records were not taken at the canning stage since the cost of harvesting at that time is considerably greater, but no doubt more accurate when estimating yields that canners might expect from the use of hybrid sweet corn. The corn was husked in October, the moisture content determined and the yields based on 15% moisture.

To test the significance of differences between hybrids and varieties, analysis of variance was used. To express significance, values of t are used. Tests of significance for the values of t were taken from

Wallace and Snedecor's (9) table of significant values of r, R, and t adapted from Fisher's (1) tables of t and Z.

In Table 1 are presented the results secured with Country Gentleman sweet corn.

If the 1931 hybrids are grouped as a whole and compared with the average of the four open-pollinated strains, the mean difference in yield expressed in pounds is 5.3 ± 0.7. The value of t is 7.37, which is highly significant in favor of the hybrids. For 1932 the differences between the average yield of the hybrids and open-pollinated strains is 5.3 ± 0.6, which is also highly significant. The mean yield of any individual hybrid is significantly greater than the mean yield of the poorest open-pollinated strain for both years. However, the mean yield of each hybrid is only significantly greater than the best open-pollinated strain when the percentage increase is greater than 19% in 1931 and 16% in 1932.

TABLE 1.—*Comparison of single cross hybrids and open-pollinated strains of Country Gentleman for 1931 and 1932.*

Hybrid No.	Inbreds crossed	1931			1932		
		Mean weight in lbs.	Increase over best variety, lbs.	Percentage increase	Mean weight in lbs.	Increase over best variety lbs.	Percentage increase
B382...	910 x 1429	20.1	2.9	17	23.2	3.9	20
B384....	917 x 857	20.2	3.0	18	23.6	4.3	22
B386...	917 x 1445	19.0	1.8	11	22.0	2.7	14
B402...	1429 x 857	20.4	3.2	25	25.4	6.1	31
B410...	1445 x 871	20.4	3.2	25	23.8	4.5	23
B411...	1445 x 908	23.0	5.8	34	25.1	5.8	30
B419...	1473 x 1389	19.0	1.8	11	22.1	2.8	14
Strain I.	Country Gentleman	16.7	—0.5	— 3	19.3	0.0	0
Strain S	Country Gentleman	13.8	—3.4	—19	17.9	—1.4	— 7
Strain O	Country Gentleman	17.2	0.0	0	18.5	—0.8	— 4
Strain L	Country Gentleman	16.6	—0.6	— 3	16.3	—3.0	—16

In Table 2 when the 20 hybrids are averaged and compared with the average of the four commercial strains, the mean difference between the mean yields is 5.4 ± 0.5. The value of t is 11.52, which is highly significant. Any hybrid outyielded, significantly, the poorest variety and all the hybrids which produced 14% more corn significantly outyielded the best variety. Two inbreds which stand out as prepotent lines for yield are 1445 and 900. We find inbred 1445 occurring as the sire in the four top-ranking hybrids, while 900 occurs five times in the first nine high-yielding hybrids and the combination of the two ranks second. These Country Gentleman hybrids compare favorably in yield with many Evergreen hybrids and most of them outyield Evergreen open-pollinated strains. The

TABLE 2.—*Comparison of single cross Country Gentleman hybrids with open-pollinated varieties in 1933.*

Hybrid No.	Inbreds crossed	Mean weight in lbs.	Increase over best variety, lbs.	Percentage increase
C110......	915 x 1445	28.2	8.9	46
C103......	900 x 1445	27.1	7.8	40
C128......	1610 x 1445	26.3	7.0	36
C106......	908 x 1445	25.5	6.2	32
C105......	900 x 1621	25.3	6.0	31
C102......	900 x 1396	25.3	6.0	31
C101......	900 x 917	25.2	5.9	30
C113......	917 x 1445	24.9	5.6	29
C104......	900 x 1610	22.4	3.1	16
C123......	1396 x 1445	23.9	4.6	23
C118......	1394 x 1445	22.4	3.1	16
C130......	1621 x 915	22.0	2.7	14
C114......	917 x 1621	22.1	2.8	14
C116......	1394 x 915	21.3	2.0	10
C112......	917 x 908	21.2	1.9	9
C109......	915 x 1396	20.8	1.5	7
C108......	908 x 1621	21.1	1.8	9
C117......	1394 x 917	20.9	1.6	8
C120......	1396 x 908	20.7	1.4	7
C111......	915 x 1610	20.7	1.4	7
Strain A...	Country Gentleman	19.3	0.0	0
Strain B...	Country Gentleman	17.9	—1.4	— 7
Strain C...	Country Gentleman	18.5	—0.8	— 4
Strain D...	Country Gentleman	16.3	—3.0	—16

Country Gentleman variety as used by canners usually yields from 25 to 30% less in weight of prime ears at the canning stage than Evergreen in the corn belt. Because of increased yields the use of hybrid Country Gentleman will overcome one of the serious objections to the use of Country Gentleman as a canning corn.

In Table 3 are presented the data where the same strain of Evergreen was crossed with 11 different inbred lines. This strain of Evergreen is used by one of the largest canners of sweet corn in north central Iowa. From the standpoint of type and yield it is equal to or better than other strains of Evergreen used by canners in the corn belt. The mean yields are presented for 1932 and 1933. The mean difference between the variety-inbred crosses and the variety for 1932 is 8.3 ± 1.5 and for 1933 is 7.8 ± 1.5. The value of t for the 2 years is 5.24 and 5.62, respectively, which are highly significant differences. When comparing individual variety-inbred crosses with the variety, those with 27% or more gain in 1932 and those with 22% or more gain in 1933 are highly significant. Only two variety-inbred crosses failed to exceed the significant percentage in 1932 and only three in 1933.

In 1932 and 1933, three variety-inbred hybrids were grown in which three different strains of Evergreen used by three canners were crossed with the same inbred. In 1932, two of the three hybrids produced a significantly greater yield than the varieties. In 1933 none of the three hybrids produced significantly greater yields than

TABLE 3.—*Comparison of Jones Evergreen variety-inbred crosses with the variety.*

	1932			1933		
	Mean weight in lbs.	Increase over variety, lbs.	Percentage increase	Mean weight in lbs.	Increase over variety, lbs.	Percentage increase
JEv. x 1071	34.8	13.6	64	30.8	13.8	81
JEv. x 1078	31.0	9.8	46	24.6	7.6	45
JEv. x 757	24.5	3.3	15	17.4	0.4	2
JEv. x 1120	28.6	7.4	35	27.4	10.4	61
JEv. x 1154	31.6	10.4	50	25.1	8.1	47
JEv. x 1181	30.9	9.7	46	29.5	12.5	73
JEv. x 1216	25.5	4.3	20	22.0	5.0	30
JEv. x 1273	22.8	1.6	8	22.4	5.4	31
JEv. x 1284	25.9	4.7	22	21.1	4.1	24
JEv. x 1334	37.5	16.3	77	33.1	16.1	94
JEv. x 1501	26.4	5.2	24	25.1	8.1	47
Jones Evergreen	21.2	0.0	0	17.0	0.0	0

TABLE 4.—*Three open-pollinated Evergreen strains crossed with the same inbred.*

	Mean weight, lbs.	Increase over variety, lbs.	Percentage increase	Value of t
1932 AEv. x L84......	23.9	8.1	51	4.61*
A Evergreen.....	15.8	—	—	—
1933 AEv. x L84......	28.7	8.0	38	1.94
A Evergreen.....	20.7	—	—	—
1932 SEv. x L84......	24.1	7.0	40	4.61*
S Evergreen.....	17.1	—	—	—
1933 SEv. x L84......	27.4	4.5	20	0.81
S Evergreen.....	22.9	—	—	—
1932 JEv. x L84......	22.4	5.3	31	1.62
J Evergreen.....	17.1	—	—	—
1933 JEv. x L84......	26.1	5.0	24	1.89
J Evergreen.....	21.1	—	—	—

*Significant differences.

the varieties, although the percentage increase in yield of each variety-inbred hybrid over the corresponding variety varied from 20 to 38%. It would seem probable that increases of 20 to 38% are certainly significant, but the values for t do not show them to be such. This can be explained by the unfortunate choice of land in 1933 for the Evergreen yield tests. This land had never been used for this purpose before and the yield tests indicated the soil in the field to be heterogeneous. Several alkali spots were present, which accounted for large variations in yields from the replicates.

The yielding power and other desirable characters of early varieties of sweet corn can be greatly increased by pollinating the variety with a good inbred. Sunshine and Golden Bantam are early varieties of high quality but with considerable variation in the maturity of the

TABLE 5.—*Variety-inbred crosses of Golden Bantam and Sunshine compared with the varieties.*

	Mean weight, lbs.	Increase over variety, lbs.	Percentage increase	Value of t
		1933		
Golden Bantam-S x 33	19.2	5.3	38	2.82*
Golden Bantam-S	13.9	—	—	—
Sunshine x 33	16.5	5.7	52	2.67*
Sunshine	10.8	—	—	—
		1932		
Golden Bantam-S x 33	17.5	5.7	48	4.19*
Golden Bantam-S	11.8	—	—	—
Sunshine x 33	17.3	6.1	54	5.72*
Sunshine	11.2	—	—	—
Sunshine	11.2	1.0	10	0.87
Inbred 33	10.2	—	—	—

*Significant increases.

ears. In Table 5 data are presented to show what can be accomplished by crossing these varieties with a good inbred sire of the same general type. Inbred 33 is a 12-row early inbred secured by inbreeding the variety Sunshine. The variety-inbred hybrids when tested in 1932–33 produced significant increases over the variety. The yields of the inbred itself and the Sunshine variety are also compared and show no significant difference, but when the two are crossed the hybrid shows a significant increase over either one.

TABLE 6.—*Comparison of large types of golden sweet corn varieties with the same types of hybrids, 1933.*

	Mean weight, lbs.	Difference	Percentage of variety	Value of t
Burpee x 90	15.3	5.3	53	—
Burpee x 7	19.4	9.4	94	—
Burpee x 45	16.2	6.2	62	—
Average	16.9	6.9	69	—
Burpee	10.0	—	100	5.20*
29 x 1	38.2	20.3	114	—
28 x 69	29.2	11.3	63	—
2 x 29	35.4	17.5	97	—
69 x 2	31.1	13.2	73	—
51 x 28	33.2	15.3	85	—
Average	33.4	15.5	87	—
Golden Evergreen	18.2	0.3	1	—
Bantam Evergreen	18.2	0.3	1	—
Golden Giant	17.3	—0.6	—3	—
Average	17.9	00.0	100	10.18*

*Highly significant.

In Table 6, large types of golden sweet corn, i.e., varieties having from 12 to 18 rows, are compared with hybrids of the same type. Burpee is an early 12-row variety, earlier than Golden Bantam. When crossed with three different golden 12-row inbreds, the resulting variety-inbred hybrids averaged 69% more corn than the variety. These hybrids were not quite as early as the variety but as early as most strains of Golden Bantam. Burpee is highly susceptible to bacterial wilt. Each of the inbreds used as a sire is somewhat resistant to the disease. The resulting hybrids produced are fairly resistant to the disease.

Also, five single cross hybrids which might be classed as medium or late-season hybrids are compared with three commercial open-pollinated varieties of the same type. Highly significant differences occur when the hybrids are compared with the varieties. All three varieties are susceptible to bacterial wilt, but all the hybrids are at least partially resistant to the disease at Ames. None of these hybrids might be classed as high quality sweet corn, but neither may the varieties be so classified; but the hybrids are as good or better than the varieties in quality.

DISCUSSION

Data have been presented to show what can be expected from the use of hybrid sweet corn with respect to increased yields. However, this is not the only reason, nor perhaps the principal reason, for recommending its use to the growers of sweet corn, especially the canners of sweet corn. Other favorable characters which are not presented in the data are of importance, such as resistance to such diseases as smut, root rot, bacterial wilt, etc., more evenness of maturity, more uniformity in size of ear, etc. The market gardener will find the use of hybrid sweet corn seed to be advantageous as compared with open-pollinated varieties. These growers try to grow a wide variety of crops for the city market on relatively high-priced land. Hybrid sweet corn seed will produce for them a greater yield of marketable ears than open-pollinated varieties from the same acreage.

In any variety, even when planted on the same date, individual plants may vary as much as 2 weeks in length of time necessary for the plant to reach the flowering period. For home purposes an irregular or prolonged flowering period may be advantageous, since it increases the number of days that corn may be picked in prime condition for table use. For canning purposes the reverse of this is true, since several pickings from the same field are not feasible. All the ears from the field or a part of the field are gathered at one time; therefore the corn delivered to the canning factory contains a considerable percentage of immature and over-mature ears. The author's observations at canning factories in the corn belt would place about 70% of the ears in prime canning condition, with about 30% of the ears in an immature and over-mature stage when commercial varieties are used. Anything that can be done, in a practical way, to decrease the percentage of the latter and increase the percentage of prime ears will greatly improve the pack. Differences in flowering date and subsequent maturity may be due to environmental factors and inherent variations. Then by use of hybrids these differences in inherent variations may be reduced to the minimum. Sufficient data are offered in this paper to prove that the use of hybrid sweet corn seed will increase acre yields. Since most canners contract with farmers to grow sweet corn on a tonnage basis, increased yields may not be of interest nor of any great importance because additional acreage may be contracted in order to secure adequate tonnage. Even though no increased yield was secured from the use of hybrid seed, it would still pay the canner to use it because of the evenness of maturity which may be secured. This is bound to increase the quality of the pack, providing the hybrid corn is picked at the right stage of maturity. The cut corn per ton is greater from hybrid corn because of less "throw outs" due to improper maturity, and if the right hybrids are used less smut and other deleterious materials are present. The author (2) in a previous publication pointed out that the variation in weight of ears was reduced by more than one-half by the use of hybrids. Also, variation in maturity of ears was greater in open-pollinated varieties than in hybrids.

It has not been possible to date to increase the yields of Country Gentleman through the use of hybrid seed over open-pollinated varieties to the same extent as has been possible with Evergreen. Ears of this variety differ in appearance from those of other varieties by having an irregular or "zigzag" or "shoepeg" arrangement of the kernels. In commercial strains of the variety there is a constant recurrence of individual ears which are more or less rowed. Weatherwax (10) explains this irregular arrangement of the kernels as being due to the crowded condition of the kernels, which is the result of the development of both upper and lower flowers of the pistillate spikelet. In varieties which are rowed the lower flower remains primordial and only the upper flower functions. Huelson and Gillis (4), however, thought that irregular rowing was due to two genetic factors which controlled rowing and that the regular rowed condition was dominant over the irregular condition. Furthermore, they suggest that the rowed arrangement of the kernels may be associated with more vigorous growth and larger yields than the zigzag arrangement. If this is true than the selection of self-lines, which carry the double recessive for rowing, for the production of hybrids may result in hybrids which may not yield any more or as much as ordinary open-pollinated strains. The author has observed in testing open-pollinated strains in use by canners in yield trials that those strains which bear a larger percentage of ears with considerable rowing, as a rule, yield better. Also, the combination of self-lines which are not completely recessive for rowing usually produce greater yielding hybrids than lines which show all absence of rowing.

An economic expedient which must be taken into consideration in the production of sweet corn hybrids is the production of tillers or suckers. All corn breeders are familiar with the fact that some inbred lines are suckerless, while other lines carry from one to four or five suckers per plant. When the production of hybrids is placed on a commercial scale through the use of detasseling blocks, the tendency to produce suckers becomes of commercial importance. In producing single-cross hybrids, if the inbred used as the female parent is highly suckered, it increases the cost of detasseling. The same holds true for three-way crosses, double crosses, and variety-inbred crosses. To induce canners and other users of sweet corn seed to use hybrids, the cost of the seed must be reasonable. The cost of production of the seed can be reduced by the use of suckerless lines, particularly in the female parent. Early varieties of sweet corn tend to produce more suckers than late varieties. The same holds true for inbred lines. Many more inbred lines segregate which produce suckers in early maturing sweet corn than in those maturing late. The use of variety-inbred crosses in early corn raises the price of producing seed. Such early varieties as Golden Bantam, Sunshine, Burpee, Early Golden Market, and others bear from two to four suckers per plant. If these varieties are used as female parents in detasseling blocks, the cost of detasseling is considerably more than is the case where a suckerless inbred is used as the female parent.

It may be astonishing to the reader that such large increases can be secured by the use of variety-inbred hybrids over the variety. Field corn breeders as a rule have not been able to secure such large increases by the use of variety-inbred crosses. Perhaps the reason for this is because of better field corn varieties which are available for test. Why should variety-inbred crosses in sweet corn be so superior in yield, evenness of maturity, etc., over the variety, while such striking improvement is not secured with variety-inbred crosses in field corn? The probable answer is that varieties of field corn are superior to sweet corn varieties in uniformity, absence of deleterious characters, etc.

SUMMARY

Data have been presented to show that sweet corn hybrids will outyield open-pollinated strains from 10 to 100%. Many variety-inbred crosses will outyield the variety by 20 to 50%.

LITERATURE CITED

1. FISHER, R. A. Statistical methods for research workers. Edinburgh and London: Oliver & Boyd. Ed. 3. 1930
2. HABER, E. S. Uniformity of maturity and size of ears of hybrid sweet corn compared with commercial strains. Amer. Soc. Hort. Sci. Proc., 27 : 352–355. 1930.
3. HAYES, H. K. The commercial use of double crossed corn in Minnesota. Jour. Amer. Soc. Agron., 22 : 606–613. 1930.
4. HUELSON, W. A., and GILLIS, M. C. Inheritance of kernel arrangement in sweet corn. Ill. Agr. Exp. Sta. Bul. 320. 1929.
5. JENKINS, M. T., and BRUNSON, A. M. Methods of testing inbred lines of maize in cross bred combinations. Jour. Amer. Soc. Agron., 24 : 523–530. 1932.
6. JONES, D. F. The attainment of homozygosity in inbred strains of maize. Genetics, 9 : 405–418. 1924.
7. LINDSTROM, E. W. Prepotency of inbred sires on commercial varieties of maize. Jour. Amer. Soc. Agron., 23 : 652–661. 1931.
8. SMITH, STUART N. Genetic investigations of the physiological response of inbred lines and crosses of maize to variations of nitrogen and phosphorus supplied as nutrients. Unpublished thesis. Iowa State College, Ames, Iowa. 1933.

9. WALLACE, H. A., and SNEDECOR, G. W. Correlation and machine calculation. Rev. by G. W. Snedecor. Iowa Agr. Col. Off. Pub., 34: No. 4. 1931.
10. WEATHERWAX, PAUL. Morphology of the flowers of Zea mays. Torrey Bot. Club. Bul., 43 : 127–144. 1916.

NOTE

VARIATIONS IN SOIL TEXTURE AS REVEALED BY MOISTURE EQUIVALENT DETERMINATIONS

In a study of moisture relationships under trees,[1] the moisture equivalent of the soil was determined on samples taken at several depths and at varying distances from the tree. The soil, Merrimac coarse sand, was derived from level or nearly level terraces of sand and gravel deposited at the close of the glacial epoch, and to all appearances is quite uniform. However, there was a very significant variation in the moisture equivalent of samples of the same depth taken at 2- or 3-foot intervals. The data from two of the experiments are given in Tables 1 and 2.

TABLE 1.—*Variations in moisture equivalent under corsican pine, Pinus laricio, Rainbow plantation.*

Distance from tree, feet	Depth, inches							
	2	6	12	18	24	36	48	Mean
				East of Tree				
15	6.13	5.50	4.25	4.35	4.19	2.19	1.56	4.02
11	5.30	5.07	4.41	4.44	3.87	2.00	1.38	3.78
5	4.81	5.48	4.48	4.05	4.25	2.05	1.48	3.80
2	5.46	5.23	4.30	4.45	3.72	1.95	1.48	3.80
0	5.26	5.19	4.38	4.33	4.25	2.26	1.77	3.92
				West of Tree				
2	5.54	5.48	4.41	4.63	4.33	1.97	1.50	3.98
4	5.47	5.24	4.57	4.54	4.04	1.89	1.32	3.87
6	5.44	5.29	4.42	4.52	4.20*	1.87*	1.40	3.88
8	4.90	5.24	4.43	4.44	4.37	1.85	1.49	3.82
10	4.92	4.84	4.13	4.28	3.48	1.95	1.47	3.58
12	5.70	5.42	4.59	4.61	3.93	1.88*	1.47	3.94
14	5.10	5.29	4.59	4.59	3.46	1.82	1.45	3.76
20	5.52	5.06	4.77	4.63	2.48	1.59	1.41	3.64
23	5.51	5.31	4.67	4.57	3.10	1.73	1.74	3.80
				Mean				
	5.36	5.26	4.46	4.45	3.80	1.94	1.50	
				Standard Deviation				
	.338	.178	.165	.155	.525	.169	.121	
				Coefficient of Variation				
	6.32	3.38	3.70	3.48	13.82	8.73	8.07	

*Estimated.

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[1] LUNT, HERBERT A. Distribution of soil moisture under isolated forest trees. Jour. Agr. Res. In press.

These results are in agreement with those of Conrad and Viehmeyer,[2] who found quite pronounced variations between samples taken within a circle 1 foot in diameter in Yolo silt loam, a sedimentary soil.

Irregularities in the deposition of this soil material are the primary cause of the variations in texture as revealed by the moisture equivalent determinations. For the most part these irregularities are not discernible in the field and can be detected only when some physical test, such as the moisture equivalent, is made. Where the object of a study is to compare the moisture equivalent of different soils, the relatively small differences herein reported are not of great importance. Their real significance lies in studies involving differences in soil moisture within any one soil or closely identical types.

TABLE 2.—*Variations in moisture equivalent under black oak, Quercus rubra, Wallingford sand plain.*

Distance from tree, feet	Depth, inches							
	2	6	12	18	24	36	48	Mean
Northwest of Tree								
18	3.59	2.98	2.24	2.87	2.54	—	—	2.84
15	4.03	3.44	2.57	2.51	2.52	—	—	3.01
12	3.75	3.39	2.54	2.49	2.31	—	—	2.90
9	4.21	3.80	2.79	2.70	2.26	—	—	3.15
6	4.38	4.06	3.12	3.02	2.62	—	—	3.44
3	4.61	3.85	3.30	3.00	2.56	—	—	3.46
Southwest of Tree								
3	4.18	3.77	3.21	3.06	2.17	1.35	1.33	2.72
6	4.37	3.73	2.89	3.12	1.85	1.60	1.28	2.69
9	3.85	3.33	2.47	3.07	1.60	1.26	1.91	2.50
12	4.11	2.93	2.24	2.63	1.76	1.34	1.41	2.35
15	3.75	3.09	2.45	2.66	1.81	1.23	1.35	2.33
18	3.56	3.21	2.48	2.57	2.08	2.01	1.32	2.46
21	3.83	3.44	2.61	2.46	2.32	1.39	1.21	2.47
24	3.82	3.42	2.46	2.58	2.95	1.44	1.41	2.58
27	3.44	3.16	2.45	2.07	2.95	1.54	1.29	2.41
30	3.43	2.90	2.05	2.04	2.93	1.37	1.39	2.30
Mean								
	3.931	3.406	2.615	2.677	2.326	1.452	1.389	
Standard Deviation								
	0.342	0.344	0.356	0.323	0.418	0.214	0.183	
Coefficient of Variation								
	8.70	10.08	13.59	12.05	17.93	14.76	13.19	

The writer suggests, therefore, that in moisture studies of this nature, particularly in glacial and glacial outwash soils, the moisture equivalent determination be made on at least every other sample and preferably every sample, even though the borings are in close proximity to each other. Certainly no comparisons of the moisture content of soils in different locations is permissible without first relating such values to the moisture equivalent, wilting coefficient, or some other soil property value.—HERBERT A. LUNT, *Connecticut Agricultural Experiment Station, New Haven, Connecticut.*

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[2] CONRAD, JOHN P., and VIEHMEYER, F. J. Root development and soil moisture. Hilgardia, 4: 113–134. 1929.

AGRONOMIC AFFAIRS

A CALL FOR CROPS PAPERS

Dr. R. G. Wiggans, Department of Plant Breeding, Cornell University, Acting Chairman of the Crops Section of the Society, announces that at the annual meeting of the Society in Washington in November, there will be an opportunity for the presentation of general crops papers at the Thursday afternoon and Friday afternoon sessions. He asks that titles for papers to be given at these sessions be sent to him at Ithaca, N. Y., as soon as possible.

The Friday morning session of the Crops Section will be devoted to a discussion of the pasture situation from the crops standpoint. Special discussions will be given on this program and papers dealing with the general subject of pastures will be listed.

MEETING OF WESTERN SECTION OF SOCIETY

Professor F. N. Briggs of the College of Agriculture at Davis, California, supplies the following report on the eighteenth annual meeting of the Western Section of the Society held in conjunction with the meeting of Section O of the American Association for the Advancement of Science at Berkeley in June.

At the first session, presided over by D. E. Stephens of the Oregon Experiment Station, President of the Section, the following papers were presented:

1. Erosion in its Relation to Land Use in the Pacific Northwest. W. A. Rockie, U. S. Dept. Interior, Pullman, Wash.
2. Report on Soil Nitrogen and Organic Matter Studies at the Sherman Branch Station, Moro, Oregon. D. E. Stephens.
3. Irrigation Experiments with Spring Wheat. A. T. Bartel, U. S. Dept. of Agriculture, Tucson, Ariz.
4. Relation of Precipitation to Moisture Storage and Crop Yield. A. F. Bracken, Nephi Substation, Nephi, Utah.
5. A Possible Method of Evaluating Wheat Varieties for Resistance to Drouth. B. B. Bayles and J. W. Taylor, U. S. Dept. of Agriculture, Washington, D. C., and A. T. Bartel, U. S. Dept. of Agriculture, Tucson, Ariz.
6. The Effect of Moisture Variation on the Length of Cotton Fiber. Ralph S. Hawkins, University of Arizona, Tucson, Ariz.

Professor B. A. Madson of University of California, was chairman at the second session when the following papers were presented:

1. Effect of Smut Disinfectants on yield of Winter Wheat. A. F. Bracken, Nephi Substation, Nephi, Utah.

2. Crown and Nodal Root Development in Wheat Varieties. D. E. Stephens and R. B. Webb, Sherman Branch Station, Moro, Ore.
3. The Rate of Color Change in Alfalfa Resulting from Uniform Sun Exposure. Ian A. Briggs, University of Arizona, Tucson, Ariz.
4. The Effect of Stage of Cutting on Yield and Longevity of Stands of Alfalfa. B. A. Madson, University of California, Berkeley, Calif.
5. The Effect of Seed Injury upon the Germination of *Pisum sativum*. H. W. Hulbert and Gerald L. Whitney, University of Idaho, Moscow, Idaho.
6. Thrasher and Other Injury in Beans. H. A. Borthwick and Roy Bainer, University of California, Berkeley, Calif.

The third session was a joint meeting with the Genetics Society of America with Professor R. S. Hawkins of the University of Arizona, presiding. The following papers were presented:

1. Primary Considerations in Developing New Wheats. E. F. Gaines, Washington State College, Pullman, Wash.
2. Evidence of Field Hybridization in Beans. W. W. Mackie, University of California, Berkeley, Calif.
3. Pale, A Hereditary Chlorophyll Deficiency in Beans. Notes on the Color of Seed Coats in Beans. Francis L. Smith, University of California, Berkeley, Calif.
4. Preservation of Yield in Breeding Wheats Resistant to Bunt by the Backcross Method. Fred N. Briggs, University of California, and G. A. Wiebe, U. S. Dept. of Agriculture, Davis, Calif.
5. Variation and Correlation in Grain Yields Among 1,500 Wheat Nursery Plats. G. A. Wiebe, U. S. Dept. of Agriculture, Davis, Calif.

The fourth session was devoted to a symposium on weed control arranged by W. W. Robbins of the University of California, who was chairman. The following papers were presented:

1. A Survey of Problems of Weed Control in California. W. S. Ball, Calif. State Dept. of Agriculture, Sacramento, Calif.
2. The Comparative Efficiency of Various Tillage and Chlorate Methods in Eradicating Morning-glory, Canada Thistle, and Perennial Sow Thistle. D. C. Tingey, Utah Agricultural Experiment Station, Logan, Utah.
3. Comparative Effect of Different pH Concentrations of Solutions of Calcium Chlorate on the Eradication of Morning-glory. D. C. Tingey, Utah Agricultural Experiment Station, Logan, Utah.
4. The Eradication of *Lepidium draba*. H. W. Hulbert, L. V. Benjamin, and H. L. Spence, Idaho Agricultural Experiment Station, Moscow, Idaho.
5. A New Means of Dissemination of Nut Grass (*Cyperus esculentus*). Margaret K. Bellue. Calif. State Dept. of Agriculture, Sacramento, Calif.
6. Methods Employed in the Study of Weed Control in California. A. S. Crafts, University of California, Berkeley, Calif.

7. The Behavior of Arsenic and Sodium Chlorate When Used as Herbicides in Soils. A. S. Crafts, University of California, Berkeley, Calif.

The following section officers were elected for 1934-35: Professor B. A. Madson, University of California, *President;* J. F. Martin, U. S. Dept. of Agriculture, Pendleton, Oregon, *Secretary*. The summer meeting for 1935 will be held at the Pendleton Field Station, Pendleton, Oregon.

SHALL WE PUBLISH A VOLUME OF PROCEEDINGS?

At the annual meeting of the Society in Chicago last year the Committee on Publications gave serious consideration to ways and means of publishing the soils and crops papers presented at the annual meetings in a volume of "Proceedings" which would supplement the JOURNAL. The possibility of cooperating with the American Soil Survey Association in a joint volume of Proceedings that would embrace the papers presented before that Association as well as those presented before the Society, was also given consideration.

Obviously, the chief obstacle is the matter of expense. If attempted, the project must be financed entirely apart from the JOURNAL; also the financial details must be worked out in advance. The Committee on Publications desires to learn the sentiment of the Society with respect to the proposed volume, particularly as to how many members of the Society would be willing to subscribe to a volume of Proceedings if assured that the cost would not exceed a stated amount. Those who are interested in such a venture are requested to fill out and return the post card to be found in this number of the JOURNAL.

While it is not possible to give any very specific information as to the size of a volume of Proceedings of the annual meeting until more is known about the make-up of the program for this year, based on the experience of recent meetings it is estimated that the volume would contain four or five hundred pages, possibly more. If the project proves practicable financially, it would achieve two things, *viz.*, (1) an early and complete record of the annual meeting, and (2) release of space in the JOURNAL now occupied by papers presented at the annual meeting for the more expeditious publication of contributed material. Please let us hear from you at an early date if you are interested.

NEWS ITEMS

THE WESTERN SOCIETY of Soil Science met in conjunction with Section O of the American Association for the Advancement of Science in Berkeley, California, in June. Officers for the coming year were elected as follows: T. F. Buehrer, University of Arizona, *President;* D. S. Jennings, Utah Agricultural College, *Vice-President;* and H. D. Chapman, University of California, *Secretary-Treasurer.*

A TWO-WEEKS short course in land appraisal was held in June at the University of Illinois, in which special instruction was given in soils. About 65 men engaged in appraisal work for the Federal Land Bank were in attendance.

D. C. MAXWELL, who has been connected for several years with the Illinois Soil Survey, has resigned to join the staff of the Soil Erosion Service of the U. S. Dept. of Interior.

PROFESSOR E. A. NORTON, University of Illinois, has been granted leave of absence to take charge, under the Federal Agricultural Adjustment Administration, of sub-marginal land projects and correlation of land use in Illinois.

J. E. GIESEKING of the Division of Soil Physics at the University of Illinois was awarded the degree of doctor of philosophy at the recent Commencement.

THE SUMMER meeting of the Corn Belt Section of the Society, which was to have been held this year at the Illinois Agricultural Experiment Station, has been called off on account of the extremely abnormal crop conditions caused by drouth and chinch bugs.

PRICES for film strips issued by the U. S. Dept. of Agriculture are slightly higher for the fiscal year 1934–35, and will range from 36 to 90 cents each, depending upon the number of illustrations in the series. The majority of the 200 series that the Department has available will sell for 36 or 45 cents each. Film strips are available on such subjects as farm crops, dairying, farm animals, farm forestry, plant and animal diseases and pests, farm economics, farm engineering, home economics, and adult and junior extension work. Lecture notes are provided with each film strip purchased. A list of available film strips and instructions on how to purchase them may be obtained by writing to the Office of Cooperative Extension Work, U. S. Dept. of Agriculture, Washington, D. C.

DR. C. F. MARBUT, Chief of the Division of Soil Survey, U. S. Dept. of Agriculture, will leave for Spain the last of August for a conference on soils in Barcelona, after which he will take part in an excursion of soil specialists over the Spanish peninsula and part of northern Africa. Later, he will spend a few months as advisor on soils to the Geological Survey of China and will also visit India. He will return to the United States in the spring.

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LINKAGE RELATIONS OF THE A_2 a_2 FACTOR PAIR IN MAIZE[1]

MERLE T. JENKINS[2]

The A_2a_2 factor pair was reported by the writer[3] in 1932. Its interactions with certain other aleurone, plant, and pericarp color genes were described at that time. The linkage group to which it belonged had not been determined, although it had been tested against genes from 7 of the 10 groups. Data obtained during the past season locate this pair of genes rather definitely in the Pr-V_2 linkage group and they accordingly are presented.

Six progenies have been obtained representing backcrosses of $\frac{bt\ +}{+\ a_2}$ with the double recessive, bt-a_2. The data on these progenies are recorded in Table 1. From these data a crossover percentage of 7.3 ± 0.41 was computed. The fit is impaired by the excess of individuals in the A_2 classes. Inasmuch as the heterozygous plants were used as the pollen parents in each case, there appears to be rather definite evidence of selective action in favor of A_2 pollen over that carrying a_2.

TABLE 1.—*Data on progenies of the backcross* bt-$a_2 \times \frac{bt\ +}{+a_2}$.

Pedigree	$Bt\ A_2$	$Bt\ a_2$	$bt\ A_2$	$bt\ a_2$	Totals	Recombinations %
8712-2 X 8719-1......	16	154	184	13	367	
" X 8719-5......	15	156	221	6	398	
8712-4 X 8719-21.....	13	113	134	13	273	
" X 8719-24.....	17	156	178	14	365	
8713-2 X 8719-14.....	6	75	105	6	192	
"-4 X 8719-1......	12	103	127	3	245	
Totals.............	79	757	949	55	1,840	7.3 ± 0.41

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[1] Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, and the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, cooperating. Journal paper No. J 148 of the Iowa Agricultural Experiment Station, Ames, Iowa. Proj. No. 182. Received for publication February 7, 1934.

[2] Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3] JENKINS, MERLE T. An additional pair of factors affecting anthocyanin pigment in maize. Jour. Agr. Res., 44 : 495–502. 1932.

Two of the progenies recorded in Table 1 were backcrosses for *pr* in addition to *bt* and a_2, as follows, $pr\ bt\text{-}a_2 \times \frac{pr\ bt\ +}{+\ +a_2}$. The data on these progenies are recorded in Table 2. The numbers are small and because of the complementary action of *Pr* and A_2 in the production of aleurone color, the crossover percentages must be computed from the colored seeds. In spite of the small numbers there appears to be little doubt that the order of the genes is $pr\text{-}bt\text{-}a_2$. Using only the data from the colored seeds, the crossover percentage between *pr* and *bt* is 24.8; that between *bt* and a_2, 7.1; and that between *pr* and a_2, 28.2. The percentage of double crossovers is 1.8 and the coincidence is 102.3%.

TABLE 2.—*Data on progenies of the backcross* $pr\ bt\text{-}a_2 \times \frac{pr\ bt\ +}{+\ +\ a_2}$.

Pedigree	*Pr Bt* A_2	*pr Bt* A_2	*Pr bt* A_2	*pr bt* A_2	*Pr Bt* a_2 *pr Bt* a_2	*Pr bt* a_2 *pr bt* a_2	Recombination percentages		
							Region 1 (*Pr-Bt*)	Region 2 (*Bt-*A_2)	Regions 1 and 2
8712–2 X 8719–1..	11	5	44	140	154	13	—	—	—
8712–2 X 8719–5..	12	3	56	165	156	6	—	—	—
Totals.........	23	8	100	305	310	19	24.8	7.1	1.8

A few data have been obtained in addition to those previously published[4] on linkage tests of a_2 with genes of linkage groups other than the $Pr\text{-}V_2$ group. These data are summarized in Table 3. They all indicate independent inheritance.

TABLE 3.—*Summary of backcross linkage data on* a_2 *and genes in groups other than the* $Pr\text{-}V_2$ *group.*

Genes		Linkage phase	XY	Xy	xY	xy	Total	Recombinations %
X	Y							
A_2......	*P*	Coup.	94	97	112	117	420	49.8 ± 1.65
A_2......	*Lg*	Rep.	189	196	181	183	749	49.7 ± 1.23
A_2......	*Su*	Rep.	1,149	1,084	1,283	1,263	4,779	50.5 ± 0.49
A_2......	*Tu*	Coup.	39	32	30	35	136	45.6 ± 2.89
A_2......	*Ch*	Coup.	455	428	419	422	1,724	49.1 ± 0.81

SUMMARY

Data are presented which indicate that the A_2a_2 factor pair is located in the Pr - V_2 linkage group, with a crossover percentage between *bt* and a_2 of 7.2.

The order of the genes studied is $pr\text{-}bt\text{-}a_2$.

There appeared to be selective action in favor of pollen carrying A_2 over that carrying a_2.

[4] *Op. cit.*

A COMPARISON OF RECIPROCAL TOP CROSSES IN CORN[1]

R. R. St. John[2]

Crosses between commercial varieties and selfed lines of corn have been termed top crosses, inbred-variety crosses, and line-variety crosses. Two uses have been suggested for such crosses. Jones[3] and Lindstrom[4] have suggested utilizing them commercially instead of crosses involving two or more inbred lines, and such a procedure is being followed to a limited extent with sweet corn. Jenkins and Brunson[5] have pointed out the possibility of using top crosses as a simple means of evaluating inbred lines for use in crosses. They reported appreciable correlations for the yields of top crosses with the mean yields of several single crosses involving the corresponding inbred lines.

In practical utilization, an advantage of top crosses over three-way or double crosses lies in the simplicity of seed production. This in turn requires that the commercial variety be used as the seed parent and there are few conditions under which the reciprocal cross would be practical. In using top crosses to test inbred lines, on the other hand, a simple way of obtaining seed is to grow and detassel the inbred strains to be tested in a field of the commercial variety to be used as a pollen parent. A relatively few ears constitute an adequate sample of the inbred and the pollen from the many plants of the variety provides an excellent random sample of that. If inbreds differing materially in season are used, the variety should be planted on two or more dates to avoid selective pollination of early inbreds by earlier tasseling plants and *vice versa.*

In using the inbred lines as the seed parents the questions arise (1) whether reciprocal crosses of inbreds with a variety are equal in general and (2) the extent to which such inequalities, if any, are variable depending upon the inbreds used. If the reciprocals tend to be essentially equal, seed may be produced in whichever way is more convenient.

If the reciprocal crosses are not equal and the inequalities between reciprocals differ significantly for different inbred lines, crosses made on the inbred lines as seed parents may not give a proper indication of the relative value of the parental lines in hybrids. Data bearing on these questions are presented here.

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[1] Cooperative investigations between the Purdue University Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication February 27, 1934.

[2] Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3] Jones, D. F. The productiveness of single and double first-generation corn hybrids. Jour. Amer. Soc. Agron., 14 : 241–252. 1922.

[4] Lindstrom, E. W. Prepotency of inbred sires on commercial varieties of maize. Jour. Amer. Soc. Agron., 23 : 652–661. 1931.

[5] Jenkins, M. T., and Brunson, A. M. Methods of testing inbred lines of maize in crossbred combinations. Jour. Amer. Soc. Agron., 24 : 523–530. 1932.

EXPERIMENTAL METHODS

Inbred lines that had been selfed for six or more generations were crossed reciprocally with the Krug variety in 1931. The crosses on Krug as a seed parent were made by hand pollinating, using a mixture of pollen from several plants of the inbred line. The reciprocals were made by growing and detasseling the inbred lines in a field of Krug, which was planted on a single date.

On crosses attempted with 100 inbreds, 49 were discarded because satisfactory 10-ear seed lots were not obtained. The remaining 51 pairs of reciprocals were compared in 1932 in single row plats 14 hills long. Each paired comparison was replicated six times. Excess seed was planted and the plants thinned at the seedling stage to a comparatively uniform stand. A 50-pound sample of each cross was taken at harvest from which to determine shrinkage and shelling percentage. The ears damaged and not damaged by dry rot were separated and this damage is reported for both ear count and weight. Smut notes were taken on 30 of the pairs of reciprocals.

DATA

The mean values for the 51 crosses on Krug as a seed parent, for the reciprocal crosses, and the differences are shown in Table 1.

TABLE 1.—*Mean values for 51 crosses of Krug x inbreds and their reciprocals.*

Seed parent	Acre yield, bu.	Shelling percentage	Test weight, lbs.	Ears at harvest needed for 1 bu. shelled corn 17.5% moisture, lbs.	Percentage ears damaged by dry rots	
					By count	By weight
Krug........	76.13	81.67	60.10	72.95	6.04	4.12
Inbreds......	72.20	81.38	59.80	73.72	6.56	4.59
Difference*.	3.93	.29	.30	—.77	—.52	—.47

*Negative differences show crosses on inbreds with larger values.

The average acre yield of the 51 crosses on Krug as a seed parent exceeded that of their reciprocals by 3.93 ± 0.46.[6] Clearly, in this material, crosses made on inbreds as seed parents were inferior in productiveness as a whole to their reciprocals. This is not surprising in view of the poor seed development on most inbred strains of corn and the well-established influence of such a condition on yield.

None of the other differences shown in Table 1 are important or significant statistically, nevertheless they all indicate a slight superiority for the crosses on Krug which may well be a reflection of the same factors influencing yield.

No significant difference occurred in the numbers of smut galls between the reciprocals, the numbers being 556 and 575 for 4,739 and 4,735 plants.

An analysis was made of the variance among the yield differences between the paired reciprocals. The variance due to inbred parent

[6] Values recorded following the ± sign through this paper are standard errors.

was significantly greater than that due to error. The value of Z was 0.7603 or more than 3 times the Z for the 1% point of 0.236. Obviously, the inequalities between reciprocals differed greatly among the parental inbred lines.

Frequency distributions of the yield differences between reciprocals, arranged in classes deviating from equality by multiples of the standard error of the difference, are given in Table 2. The "expected" frequencies are based on the normal curve. Comparison between the observed and expected shows nothing to indicate that any of the crosses of inbreds x Krug were actually superior to their reciprocals. The excess numbers of differences in favor of the crosses on Krug in the cells representing 2.5 or more times the standard error, on the other hand, are clear evidence of their superiority. That is, some of the reciprocals were equal; in others the cross on Krug was superior; but in none is there conclusive evidence of superiority of the cross on the inbred as seed parent.

TABLE 2.—*Frequency distribution of the yield differences between 51 pairs of reciprocal crosses of inbred lines with the Krug variety.*

	Class centers in multiples of the standard error*									
	Inbred x Krug exceeds				Krug x inbred exceeds					
	3.5	2.5	1.5	0.5	0.5	1.5	2.5	3.5	4.5	10.5
Observed........	1	1	4	7	13	10	8	3	3	1
Expected........	0.1	1.1	6.9	17.4	17.4	6.9	1.1	0.1	—	—

*The standard error used (± 3.26 bushels) is that due to experiment apart from differential behavior of the different crosses.

Pollination records showed that the mean date of silking was 5 days earlier for Krug than for the average of the 51 inbreds. Corn plants generally shed pollen from 1 to 3 days before silking. There consequently was little or no difficulty in making any of the desired crosses on Krug as a seed parent. In producing the reciprocal crosses by detasseling the inbreds in a field of Krug, however, the later blooming inbreds were pollinated with pollen from a relatively few late-tasseling Krug plants. With this in mind, the reciprocals were compared for yield in three groups, based on relative date of shedding pollen by the inbred parents. The comparison is shown in Table 3. The difference between the differences for groups 1 and 2 is not large and only slightly larger than its standard error (± 1.12). The difference between groups 1 and 2, on the one hand, and group 3 on the other, however, are 4 or more times their standard error. Whether this is because of selective pollination or some other cause is not clear.

DISCUSSION

It seems clear from the experiments here reported that the yield of a cross of a commercial variety on an inbred can not be taken as an accurate criterion of the productivity of its reciprocal. The crosses on the variety as seed parent not only tended to yield more as an

TABLE 3.—*Comparison of reciprocal crosses for yield grouped on the basis of date of shedding pollen of the inbred parents.*

Group	Maximum pollen shedding	Pairs of reciprocal crosses with yields favoring seed parent stated			Average difference in acre yield
		Krug	Inbred	Total	
1, Early	On or before July 25	12	5	17	2.83 ± 0.79
2, Medium	July 26–29	11	6	17	1.46 ± 0.79
3, Late	July 30 or later	15	2	17	7.60 ± 0.79
Total or average		38	13	51	3.93 ± 0.46

average, but the tendency was variable, with many of the reciprocals yielding equally, within the limits of error in the experiment. Accordingly, comparisons of the yields of top crosses with those of varieties, double crosses, etc., may not adequately measure the productive capacity of the inbreds if the top crosses have been made on the inbreds as seed parents.

Furthermore, the variation among the differences between reciprocals indicates that comparisons of the value of inbreds for crossing based on crosses of these inbreds by a commercial variety may be distorted. It is highly probable that some of this variation is because of differences in seed quality among the inbreds. If these differences in seed quality are due to inherent inability to mature properly because of disease susceptibility or the like, a reflection of their influence on yield in testing the inbreds may be desirable. Where the differences are due only to size and general quality resulting from variation in the vigor of the inbred plants on which the seed is produced, reflection of their influence probably is undesirable. Where the inbreds are being tested for use in double crosses, the seed quality of the inbred lines is of minor consequence.

The variation between reciprocals in the three groups based on time of silking of the parent inbreds suggests that more than seed quality may be involved. This is not certain as there might easily have been a relation, accidental or otherwise, between poor seed quality and lateness in the material used. The possibility remains, however, that selective pollination by the later Krug plants also may have been a factor.

SIZE, SHAPE, AND REPLICATION OF PLATS FOR FIELD EXPERIMENTS WITH COTTON[1]

E. B. REYNOLDS, D. T. KILLOUGH, AND J. T. VANTINE[2]

A large amount of work on methods of conducting field plat experiments has been conducted in Europe and America. In this country the American Society of Agronomy, since its organization in 1907, has encouraged systematic studies on plat technic for various kinds of field experiments. The Society has adopted and published recommended standards for field experiments, together with a rather extensive bibliography (4).[3] Although these standards provide guiding principles for conducting field experiments, there is little published information on methods of conducting field trials with cotton.

Recently, Ligon (5) in Oklahoma reported results on size and replication of plats for cotton. He concluded that the rows need not be longer than 100 feet and suggested three replications for variety tests of cotton.

Bailey and Trought (1) in Egypt published a paper on the error of field trials with cotton. Their work was conducted under irrigation and handled quite differently from the usual way of conducting cotton field trials in America. They concluded that 10 replications of plats about one-fifth of an acre in size should be used and the test repeated at least 3 years to give reliable results.

METHODS

In 1931 cotton yield data from a blank experiment were collected at the main experiment station, College Station, Texas, from 48 36-inch rows 300 feet long. The rows were harvested in 48-foot sections, making a total of 288 plats (rows) each 0.0033 acre in size. A similar blank experiment was conducted in 1932 at Substation No. 12, Chillicothe, Texas, on 48 rows, 282 feet long and 40 inches wide. The rows were harvested in 47-foot sections, making a total of 288 plats, each 0.0036 acre in size. The yield of cotton from the plats was stated in pounds of lint per acre.

Analysis of variance was used in making a statistical study of the data. No attempt is made to describe the details of the calculations since adequate discussions have been published by Fisher (2), Snedecor (6), and others. In each phase of the work the fields were divided into blocks that would have accommodated 12 varieties or treatments. The variety is constant so that the variance that would have been attributed to varieties or treatments in an actual experiment was not taken out. The variation within blocks was taken as the experimental error and from it the standard deviations and standard errors were calculated.

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[1] Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Tex. Technical Paper No. 273. Received for publication October 31, 1933.

[2] Chief of Division of Agronomy, Agronomist, and Assistant in Agronomy, respectively. The authors are indebted to J. O. Beasley, Assistant in Agronomy, for valuable assistance in the statistical treatment of the data, and to J. R. Quinby, Superintendent, Texas Substation No. 12, Chillicothe, Tex., for obtaining the field data at that point in 1932.

[3] Figures in parenthesis refer to "Literature Cited," p. 734.

SIZE OF PLAT

The size of plat is considered under two conditions. In the first, the experimental area is kept constant and the number of replications varies inversely with the size of plat. In the second, the experimental area is increased in proportion to size of plat and the number of plats is constant.

WITH AREA CONSTANT

This part of the study considers the size of plat where it is assumed that the amount of land available for field experiments is limited, thus making it necessary to reduce the number of plats if the size is increased or to reduce size when the number is increased.

For the one-row 48-foot plat the total area at College Station provided 24 blocks, with 12 hypothetical varieties to the block. There were 12 blocks of 96-foot plats, 8 blocks of 144-foot plats, and 4 blocks of 288-foot plats. The analysis of variance for the 96-foot plats is shown in Table 1. The data obtained at Chillicothe were analyzed in a similar manner.

TABLE 1.—*Analysis of variance of cotton yield data from 12 blocks each composed of 12 single-row 96-foot plats, College Station, Texas.*

Variance due to	Degrees of freedom	Sum of squares	Variance	Standard deviation	Standard error
Blocks	11	33,633			
Within blocks	132	189,051	1,432.205	37.84	10.92
Total	143	222,684			

With the area constant, the standard error (standard deviation divided by the square root of the number of replications) increased as the size of plat was increased at both College Station and Chillicothe, as shown in Tables 2 and 3. The standard error was least for the smallest plats, showing that the smaller the plat the more efficiently a given area of land may be used. If the experimental area is limited, the standard error can be reduced only by increasing the number of plats, which means that the size must be decreased.

TABLE 2.—*Standard errors of the mean in pounds of lint per acre of plats varying in size and shape, with the area constant, College Station, Texas.*

Width in rows	Length in feet			
	48	96	144	288
1	9.02	10.92	12.32	14.55
2	10.63		14.38	
3	10.61	12.67		
6	13.03			

The efficiency of plats of various sizes with the area constant was calculated on a percentage basis by dividing the standard error of the smallest plat by the standard error of larger plats and multiplying by

TABLE 3.—*Standard errors of the mean in pounds of lint per acre of plats varying in size and shape, with the area constant, Chillicothe, Texas.*

Width in rows	Length in feet			
	47	94	141	282
1	6.27	6.98	7.67	9.34
2	8.78		15.59	
3	14.65	21.58		
6	23.47			

100 (Tables 4 and 5). On this basis one-row plats 96 feet long were only 82.6% as efficient as one-row plats 48 feet long.

TABLE 4.—*Percentage efficiency of plats of various sizes and shapes, with the area constant, College Station, Texas.*

Width in rows	Length in feet			
	48	96	144	288
1	100.0	82.6	73.2	62.0
2	84.9		62.7	
3	85.0	73.5		
6	69.2			

TABLE 5.—*Percentage efficiency of plats of various sizes and shapes, with the area constant, Chillicothe, Texas.*

Width in rows	Length in feet			
	47	94	141	282
1	100.0	89.8	81.8	67.1
2	71.4		40.2	
3	42.8	29.1		
6	26.7			

WITH AREA IN PROPORTION TO SIZE OF PLAT

The object of this part of the study is to find a desirable size of plat when the amount of land is not a limiting factor.

In studying the size of plat with the area varying in proportion to size, it is necessary to hold the number of replications constant. This means that the area occupied by 48-foot plats would be only half of that occupied by 96-foot plats, and that the standard deviation for the 48-foot plats would vary, depending upon which half of the area was used. Under such a condition the best figure to represent the standard deviation for the 48-foot plats would be an average of two standard deviations calculated from each half of the area occupied by 96-foot plats. The same average standard deviation for the 48-foot plats can be calculated from the average variance within blocks for the entire area occupied by the 96-foot plats. The last method was used in this study, that is, the entire area was used with each size of plat, making the standard deviation for all except the larger size of plat average standard deviations. The standard deviation for the largest size of plat was based upon four replications.

At College Station, with the number of replications constant, increasing the size of plat by increasing either the length or width reduced the standard error of a single replicate (standard deviation) as shown in Table 6. Increasing the length of plat at Chillocothe reduced the standard error of a single replicate (Table 7).

TABLE 6.—*Standard deviations in pounds of lint per acre of plats varying in size and shape, College Station, Texas.*

Width in rows	Length in feet			
	48	96	144	288
1	44.19	37.84	34.86	29.11
2	36.82		28.77	
3	30.00	24.54		
6	26.06			

TABLE 7.—*Standard deviations in pounds of lint per acre of plats varying in size and shape, Chillicothe, Texas.*

Width in rows	Length in feet			
	47	94	141	282
1	30.73	24.16	21.68	18.67
2	30.40		31.19	
3	41.43	43.16		
6	46.93			

The percentage efficiency of plats of different sizes in the use of land may be calculated by finding the number of replications required to give the same standard error for each size of plat, multiplying the number of replications by the size of plat to give the area of land required for each size of plat, and then dividing the area required for the smallest plat by the area required for larger plats and multiplying by 100. An easier way of securing the same result is to divide the standard error of the mean squared of the smaller plats by the standard error squared of the larger plats and multiplying by 100. The efficiency of plats may also be found by using Immer's (3) method of comparing the variance per unit area of plats varying in size and shape. For example, the efficiency of plats double the unit size was found by dividing the variance of the unit plats by two times the variance of plats double the unit size. It is obvious from Tables 8 and 9, which give the percentage efficiency of plats of different sizes, that small plats make the most efficient use of the land. For instance, at College Station one-row plats 48 feet long required only 53.6% as much land as one-row plats 144 feet long to give the same standard error.

When the size of plat is increased by extending it in the direction of greatest soil variation, the standard deviation will be reduced. If the size is increased by extending in the direction of least variation, the standard deviation will not be reduced, but in some cases actually increased. For example, at Chillicothe the standard deviation for one-row plats 47 feet long was 30.73, while that for three-row plats 47 feet long was 41.43 (Table 7).

TABLE 8.—*Percentage efficiency in use of land with plats varying in size and shape, College Station, Texas.*

Width in rows	Length in feet			
	48	96	144	288
1	100.0	68.2	53.6	38.4
2	72.0		39.3	
3	72.3	50.7		
6	47.9			

TABLE 9.—*Percentage efficiency in use of land with plats varying in size and shape Chillicothe, Texas.*

Width in rows	Length in feet			
	47	94	141	282
1	100.0	80.7	66.8	45.1
2	51.0		16.2	
3	18.3	8.4		
6	7.1			

The smallest plats studied (47 and 48 feet long) made the most efficient use of the land, but it required several more replications to give a standard error as small as that found from plats of twice the length (Tables 10 and 11). Further increase in size of plat would not greatly reduce the number of replications required, but it would greatly increase the amount of land and labor. For these reasons one-row plats approximately 100 feet long would be satisfactory, and variations in length from 50 to 150 feet also would be satisfactory with suitable changes in the number of replications.

TABLE 10.—*Theoretical number of replications required to give a standard error of the mean of 14.6 pounds of lint per acre with plats of different sizes and shapes, College Station, Texas.*

Width in rows	Length in feet			
	48	96	144	288
1	9.2	6.8	5.7	4.0
2	6.4		3.9	
3	4.2	2.8		
6	3.2			

TABLE 11.—*Theoretical number of replications required to give a standard error of the mean of 9.3 pounds of lint per acre with plats of different sizes and shapes, Chillicothe, Texas.*

Width in rows	Length in feet			
	47	94	141	282
1	10.8	6.7	5.4	4.0
2	10.6		11.2	
3	19.7	21.4		
6	25.3			

SHAPE OF PLAT

In addition to knowing the size of plat for cotton, it is desirable to know the most efficient shape. This problem was studied by finding the standard error of plats of the same size but of different shapes. In comparing plats of the same size but of different shapes, the area was divided into blocks of unit plats that remained the same for the different shapes of plats so that the variance caused by blocks was constant, and any difference in the variance within blocks resulted from changing the shape of plats.

Shape of plat had no significant effect on plat variability at College Station (Table 6). At Chillicothe, however, the short, wide plats were more variable than the long, narrow plats of equal size (Table 7).

In general, long, narrow plats seemed to control soil heterogeneity more efficiently than short, wide plats, because this shape of plat has a better chance of taking in all soil differences.

NUMBER OF REPLICATIONS

The effect of changing the number of replications was determined along with the size and shape of plat. This problem was studied by forming the area at College Station into 144 one-row plats 96 feet long and the area at Chillicothe into 144 one-row plats 94 feet long. At both points the plats were formed into 12 blocks with 12 hypothetical varieties in each. For two replications the standard deviation of the first two blocks was divided by the square root of 2 to give the standard error, and then one block at a time was added and the standard error calculated until all 12 blocks were used. It is obvious that the area of land fluctuates in proportion to the number of replications.

Theoretical standard errors were calculated for each number of replications (ranging from 2 to 12) by dividing the standard deviation based on the variance within blocks of the total area by the square root of the number of replications. The actual and theoretical standard errors are plotted as curves in Figs. 1 and 2.

At College Station the actual standard error was higher than the theoretical for all except the twelfth replication, in which case the two were equal. This resulted from the fact that the first three blocks had a much higher variance within blocks than the average of all the blocks. If the variance within the first blocks had been less than the average variance for all the blocks, the actual standard error for the first replications would have been less than the theoretical—a result that was actually obtained at Chillicothe. Any deviation of the actual from the theoretical standard error is caused by the sampling error in the selection of blocks to make a given number of replications. For this reason any attempt to estimate the reduction in standard error expected by increasing the number of replications should be made from the theoretical curve.

When the variance caused by blocks is removed, as was done in this study, increasing the number of replications will not increase the variability so long as the variance within blocks added is not higher than the variance in the blocks used with the smaller number of replications. This means that added blocks may differ widely in yielding ability without affecting the standard error. If increasing the number of replications necessitates taking in blocks with much higher variance, the standard error will not be lowered, but in some cases will actually be increased. For example, the standard error of eight replications at Chillicothe was greater than the standard error of seven replications (Fig. 2). If the added blocks have no more variance than the first blocks, the standard error can be reduced to almost any desired level by increasing the number of replications.

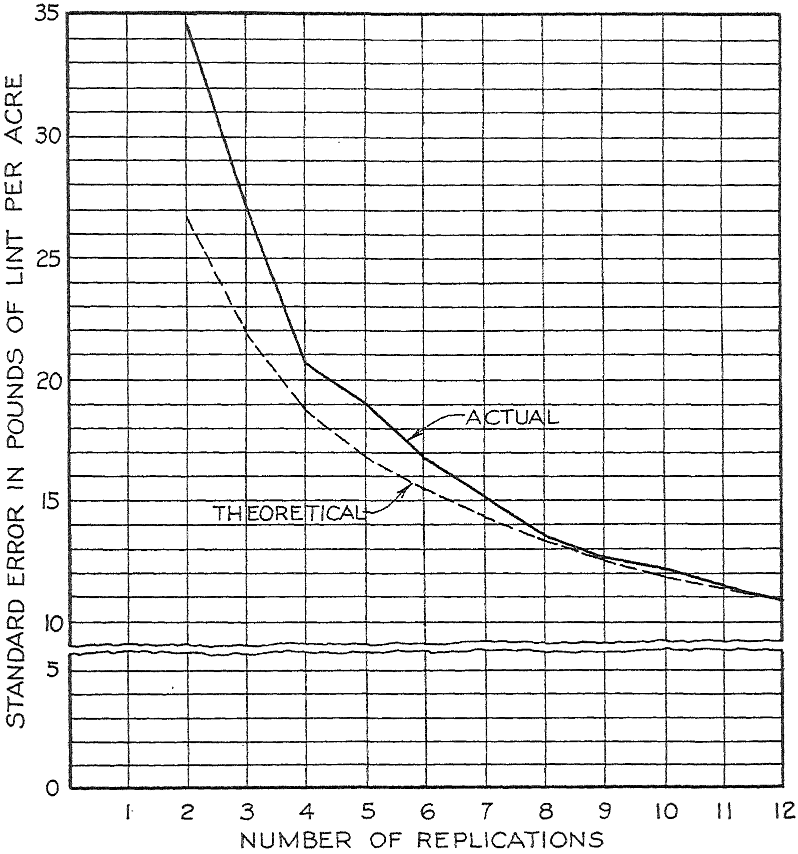

FIG. 1.—Actual and theoretical reduction in standard error due to increasing replication of plats at College Station, Texas.

By observing the theoretical curves in Figs. 1 and 2, it may be seen that the reduction in the standard error is rapid until about the sixth replication, when the rate of reduction decreases markedly. Calculating from the theoretical curve, one can ordinarily expect to reduce the standard error 29.3% by increasing the number of replications from 2 to 4; 18.3% from 4 to 6; 13.4% from 6 to 8; 10.5% from 8 to 10; and 8.8% from 10 to 12.

This study indicates that for field experiments with cotton there should be a minimum of six replications. If greater accuracy is desired, the number of replications should be increased accordingly. As shown in Tables 2 and 3, increasing the number of replications is decidedly more effective in reducing the standard error than increasing the size of plat.

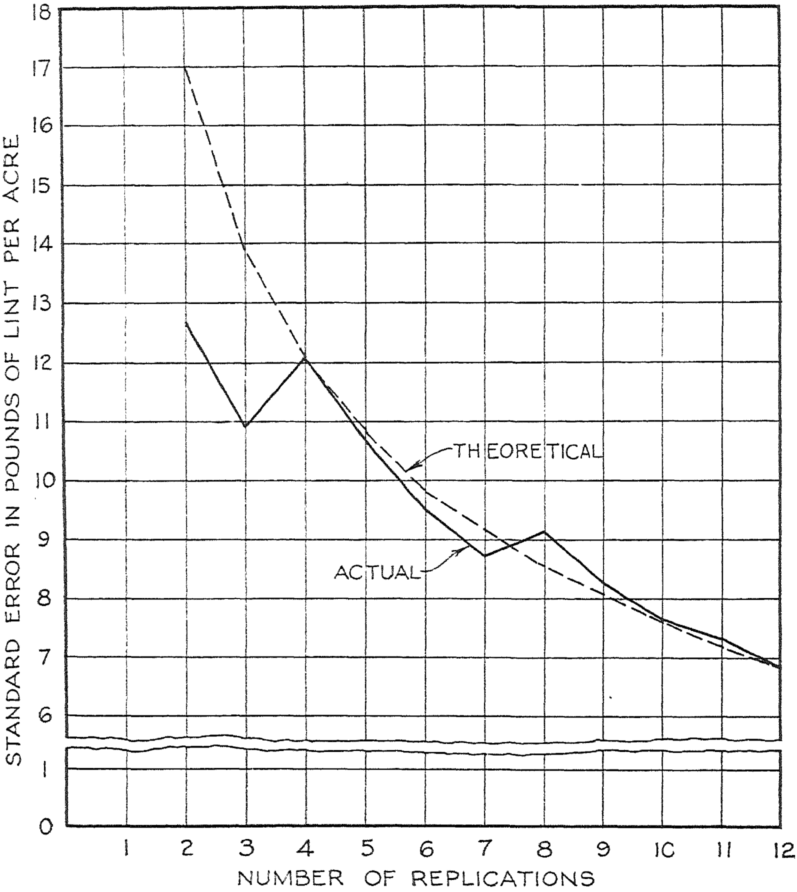

FIG. 2.—Actual and theoretical reduction in standard error due to increasing replication of plats at Chillicothe, Texas.

DISCUSSION OF RESULTS

In planning a field experiment with cotton or other crops, the first step should be to decide what standard error would be desirable for the particular experiment. Then it would be necessary to find the size, shape, and number of replications of plats required to obtain the desired accuracy.

In these studies it was found that increasing the size of plat from 48 to 96 feet in length reduced the standard deviation considerably, but further increase in size of plat did not reduce the standard deviation in proportion to the amount of land required (Tables 6 and 7). The smallest plats made the most efficient use of the land, for they required much less land than the larger plats to give the same standard error of the mean (Tables 8 and 9). Where the amount of land is limited, the standard error can be reduced only by using small plats and a large number of replications. Obviously, however, there is a practical limit to which the size of plat may be reduced. The lower limit in size of plat is governed by the number of plants required to give a fairly reliable sample of the variety. It has been found at the Texas Station that at least 30 plants of cotton should be used for this purpose.

In general, long, narrow plats gave smaller standard errors than short, wide plats. This study did not involve a consideration of border effect and the sizes of plat given are for the harvested area.

The results obtained indicate that in the usual type of field experiments with cotton a minimum of six replications should be used, for until this number is reached increasing the number of replications is the most effective means of reducing the standard error.

Further, the experimenter is interested in the efficiency of the size, shape, and replication of plats as related to the amount of land, labor, machinery, and other facilities available. Considering, for example, the efficiency of various sizes of plats at College Station, it was shown that one-row plats 48 feet long required only 53.6% as much land as one-row plats 144 feet long to give the same standard error (Table 8). This means, of course, that the efficiency is increased by the use of smaller plats with more replications. When one-row plats were used, it was found that 10 replications of 48-foot plats, 7 replications of 96-foot plats, and 6 replications of 144-foot plats were required to give the same standard error as 4 replications of 288-foot plats at College Station (Table 10). Somewhat similar results were obtained at Chillicothe (Table 11). The standard error of the mean multiplied by the square root of 2 and then multiplied by 2 will give the size of a mean difference that would be significant, with odds of approximately 19 to 1. For the sizes of plats with their corresponding number of replications given in Tables 10 and 11, a significant mean difference would be 41.2 pounds of lint per acre at College Station and 26.4 pounds at Chillicothe.

In conducting field trials with cotton the investigator has several alternatives in the matter of size and replication of plats, as shown above. Where the amount of land is not limited, plats 100 to 150 feet long replicated six or seven times might be the best arrangement. In cases where the amount of land is limited, the use of smaller plats, 50 to 100 feet long, replicated enough to give the same accuracy would result in more efficient use of the land.

SUMMARY

A blank experiment was conducted at College Station, Texas, in 1931, and at Chillicothe, Texas, in 1932, to determine the proper size, shape, and number of replications of plats for field experiments with cotton. Analysis of variance was used in making a statistical analysis of the data.

The results obtained indicate that the research worker has a considerable range in selecting size and replication of plats, depending on the amount of land at his disposal. Where the amount of land is not limited, the use of plats 100 to 150 feet long replicated six or seven times would be satisfactory. In cases where only a small amount of land is available, smaller plats, 50 to 100 feet long, with more replications to give the same accuracy would result in more efficient use of the land.

The shape of plat had no significant effect on variability at College Station, but long, narrow plats were less variable than short, wide plats of the same size at Chillicothe. In general, long, narrow plats are to be preferred.

LITERATURE CITED

1. BAILEY, M. A., and TROUGHT, T. Error of field trials with cotton in Egypt. Egyptian Min. Agr., Bul. 63. 1926.
2. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1932.
3. IMMER, F. R. Further studies of size and shape of plot in relation to field experiments with sugar beets. Jour. Agr. Res., 47 : 591–598. 1933.
4. Standardization of field experiments. Jour. Amer. Soc. Agron., 16 : 1–16; 804–805. 1924; 22 : 1056–1061. 1930; 23 : 1021–1023. 1931; 24 : 990–992. 1932; 25 : 803–828. 1933.
5. LIGON, L. L. Size of plat and number of replications in field experiments with cotton. Jour. Amer. Soc. Agron., 22 : 689–699. 1930.
6. SNEDECOR, GEORGE W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press, Inc. 1934

A COMPARISON OF THE SURFACE, FURROW, AND LISTED METHODS OF PLANTING CORN[1]

MERLE T. JENKINS[2]

Experiments conducted under conditions of infestation by the European corn borer have shown that infestation is correlated with the relative maturity of the corn plants at the time of moth flight. This correlation obtains regardless of whether the differences in relative maturity are the result of differences in time of planting or are produced by various methods of retarding the early growth of the plants. Preliminary comparisons of the effect of several methods of retarding early growth upon infestation[3], indicated the listed method of planting to be very effective in reducing infestation. In anticipation of the possible use of this practice in combating the corn borer in the corn belt, experiments were begun in 1928 to determine the practicability of listing and of planting corn in furrows under central Iowa conditions.

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[1] Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, cooperating. Journal paper No. J178 of the Iowa Agricultural Experiment Station. Received for publication March 2, 1934.

[2] Principal Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3] SALTER, ROBT. M., THATCHER, L. E., and MCCLURE, J. T. Agronomic research on the European corn borer in Ohio. Jour. Amer. Soc. Agron., 20 : 1011–1032. 1928.

HUBER, L. L., NEISWANDER, C. R., and SALTER, R. M. The European corn borer and its environment. Ohio Agr. Exp. Sta. Bul. 429. 1928.

EXPERIMENTAL PROCEDURE

Listing and furrow planting were compared with the ordinary level or surface planting. The furrows were made with disc furrow openers attached to the corn planter and the listing was done with a 2-row lister. All of the comparisons were in four-row plats approximately 1/20 acre in size. There were three plats of each method of planting in each season. The outside rows of each plat were discarded and the yields based on the two central rows. Rows were spaced 40 inches apart and seed was dropped in the rows to give an equivalent of three plants per 40 inches. The soil on which the experiment was conducted is a rather heavy Webster silt loam merging into a Carrington silt loam at one end of the field.

Considerable difficulty was experienced in obtaining comparable stands by the different methods of planting. With the exception of 1928, the seed was dropped by hand at double thickness and thinned to as near comparable stands as possible. In 1928 and 1929 the stands of the furrow and lister plantings were so irregular that yields were obtained by harvesting short sections of equal numbers of plants from areas with the most comparable stands. This gave some advantage to the furrow and listed plats in that the areas sampled in these plats were slightly larger than in the level plantings, but it was the best that could be done under the circumstances. The stands in 1930, 1931, and 1932, while not strictly comparable, were considered sufficiently so to harvest all of the two central rows.

All plats were fall plowed. This practice ordinarily is not followed where the lister method of planting is used. Under the conditions of the experiment, however, it was not convenient to leave unplowed in the fall the plats which were to be listed and accordingly they were plowed along with the rest. Seedbed preparation in the spring was uniform for all plats up to the time they were prepared for planting. After planting, the different methods of planting were cultivated according to their respective needs.

The corn varieties used in planting the experiment in the different seasons were in 1928, McCulloch Yellow Dent; in 1929, Krug; in 1930, Iodent; and in 1931 and 1932, Krug. The yields are expressed as bushels of shelled corn per acre with 15.0% moisture.

EXPERIMENTAL RESULTS

As an average for the 5-year period, the level method of planting yielded 67.6 bushels per acre, the furrow method (furrow openers) 65.7 bushels per acre, and the lister method 70.0 bushels per acre (Table 1). The total number of plants for the three methods for 1930, 1931, and 1932 are given in Table 2. The stands for 1928 and 1929 are not given as the yields were obtained from equal numbers of plants.

TABLE 1.—*Acre yields of corn in bushels from three methods of planting, 1928–1932.*

Method of planting	1928	1929	1930	1931	1932	Mean
Level	89.0	57.2	34.7	83.1	74.0	67.6
Furrow	95.3	51.1	34.6	83.7	63.8	65.7
Listed	93.8	69.7	32.1	79.2	75.3	70.0

TABLE 2.—*Summary of the total numbers of plants for the 3 methods of planting.*

Method of planting	1930	1931	1932
Level	1,721	1,882	1,917
Furrow	1,410	1,868	1,922
Listed	1,230	1,812	1,915

An analysis of the data indicated that the variance due to planting method was not large enough to indicate significant differences among the yields of the different methods. The standard error of the 5-year means is 3.3 bushels. There is considerable difference in the ranking of the planting methods in the different seasons, indicating that the nature of the season has much to do with the relative merits of the methods. The seasonal differences in stands may have contributed somewhat to this variability.

A summary of the data on plant characters is recorded in Table 3. Records were not taken on all of the characters over the entire duration of the experiment. The number of seasons during which the data on each character were taken is indicated in the footnotes.

TABLE 3.—*Summary of the plant characters for three methods of planting, 1928–1932.*

Plant characters	Method of planting		
	Level	Furrow	Listed
Plant height, feet*	8.3	8.5	8.3
Ear height, inches*	40.9	38.5	38.5
Stalks per plant, number†	1.02	1.03	1.01
Plants erect at harvest, %*	24.1	28.9	31.7
Plants leaning at harvest, %*	32.6	30.7	33.2
Plants down at harvest, %*	10.2	7.3	4.2
Plants broken at harvest, %*	33.2	33.1	30.5
Ears per cwt., number*	236	227	214
Shelling percentage‡	84.1	84.0	83.3
Test weight of grain per bu., lbs.†	56.2	56.2	56.1
Moisture in grain, %‡	24.1	24.5	26.3
Date ¼ silked, days after June 30§	31.5	29.8	32.7
Date ¼ tasseled, days after June 30§	30.0	27.1	31.0

*Data taken in 4 of the 5 seasons.
†Data taken in 3 of the 5 seasons.
‡Data taken in all 5 seasons.
§Data taken in 2 of the 5 seasons.

The differences between the planting methods are essentially those that would be expected. The furrow and listed plantings had slightly lower ears, more plants erect at harvest, and had somewhat larger ears (fewer ears per cwt.) than the level planting. The listed planting was later in tasseling and silking and had more moisture at harvest than the level and furrow plantings. An analysis of the data indicates that the variance due to method of planting was large enough to indicate significant differences among the planting methods for the following plant characters: Stalks per plant, ears per cwt., shelling percentage, and date ¼ tasseled.

Listing is more suited to the lighter soil types and drier climates.

In Iowa, when the rainfall is relatively high, the type of soil is of special importance. In general, it is to be expected that the heavier the soil the lower will be the soil temperature at the bottom of the lister furrow and the more the early growth will be retarded. If, as in these experiments, this retardation does not result in lower yields from the listed plantings, it might be assumed that listing could well replace level planting, especially under conditions which make the retardation of early growth desirable.

Experience during the progress of these investigations has indicated certain practical difficulties connected with the handling of listed corn on heavy soil. The greatest difficulty encountered was the tendency of the lister to turn up large clods which baked in the sun. This condition made the first and second cultivations extremely difficult to accomplish without serious injury to the stand in the listed plats. Under farm conditions with soils of this type, there is doubt as to whether satisfactory stands would be obtained.

If suitable machinery or special methods can be developed for handling the heavier soil types so as to insure good stands, the practice of listing might increase in favor in the corn belt. In sections where it can be used, it offers the most economical method for corn production.

SUMMARY

The surface, furrow, and listed methods of corn planting were compared for a 5-year period. Yields from the three methods of planting were not significantly different, but considerable extra care was required to obtain comparable stands in the listed plantings.

Data are reported on the influence of method of planting upon a number of characters of the corn plant.

EFFECT OF CHEMICAL SOIL TREATMENTS ON THE ROOT, CROWN, AND SHOOT ROT OF MILO[1]

H. E. MYERS[2]

A disease of milo that may become serious in regions where milo is grown extensively has recently been described.[3] When the diseased condition first appeared there was some speculation as to the cause. However, it has been fairly well established that it is caused by some undetermined micro-organism that lives over in the soil and that can be destroyed by sterilizing the soil in which it occurs. Since several pathological conditions in plants have been shown to be the result of or, at least, influenced by an unbalanced nutrient condition in the soil, it seemed desirable to study the influence of soil treatment on this disease.

[1] Contribution No. 233, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication, March 6, 1934.

[2] Assistant Professor of Soils. The author wishes to express his appreciation to Dr. M. C. Sewell, formerly of this station, and to Dr. John H. Parker, for their encouragement and interest in this investigation.

[3] ELLIOT, CHARLOTTE, WAGNER, F. A., and MELCHERS, L. E. Root, crown, and shoot rot of milo. Phytopath., 22 : 365–367. 1932.

MORGAN, ALVIN. A new milo disease in the southwest. Kan. Agr. Student, 12 : 83–84. 1933.

A greenhouse experiment was therefore set up making use of soil from a field at the Garden City, Kan., experiment Station taken from an area where milo previously had been observed to be badly diseased and from another area where no evidence of the disease had been noted. Each soil was mixed thoroughly and potted in glass battery jars, using the same weight of soil in each jar. All treatments, with the exception of sulfuric acid, were applied to the surface of the soil and worked in with a spatula just prior to planting. The sulfuric acid was thoroughly mixed with the soil and the soil left exposed to the air for at least 24 hours before repotting. All watering was done with distilled water. The soil was maintained at favorable moisture content by weighing and watering as needed. All treatments were based upon the surface area of the soil in the jars.

The soil from the disease-producing area at Garden City received the following treatments:

1. Varying proportions of nitrogen as calcium nitrate, phosphorus as 16% superphosphate, and potassium as potassium chloride.
2. Sodium nitrate C. P., 300 lbs. per acre.
3. Ammonium nitrate C. P., 200 lbs. per acre.
4. Boric acid C. P., 2 lbs. per acre.
5. Sulfur flowers, 300 lbs. per acre.
6. Sulfur flowers, 1,000 lbs. per acre.
7. Sulfuric acid C. P., 150 lbs. sulfur per acre.
8. Sulfuric acid C. P., 300 lbs. sulfur per acre
9. Ammonium sulfate C. P., 300 lbs. per acre.
10. Magnesium sulfate C. P. $MgSO_4$, 500 lbs. per acre.
11. Manganous sulfate C. P. ($MnSO_4.2H_2O$), 150 lbs. per acre.
12. Copper sulfate C. P. $CuSO_4$, 50 lbs. per acre.
13. No treatment

Five pots of untreated, non-disease-producing soil were used as controls. Self-pollinated seed of dwarf yellow milo was used in all trials. Three crops were grown, two during mid-winter and the third during the spring months, in the same soil, but the treatments were applied prior to seeding each new crop.

EXPERIMENTAL RESULTS

While some very striking differences developed in the treated soils, there was no single treatment or combination of treatments that produced plants comparable to the plants growing in the disease-free soil. This is shown in Fig. 1, a photograph of representative plants of several treatments taken at the time the milo on the control soil was beginning to head.

The only beneficial effect obtained was from the applications of nitrogen. All plants grown in soil with other treatments died as quickly as did those in the non-treated soil, while most of the plants in the pots where a nitrogen carrier was added remained green until the experiment was discontinued. Even with nitrogen treatments some of the plants died.

Ammonium nitrate at 200 pounds per acre and sodium nitrate and ammonium sulfate each at 300 pounds per acre seemed to be about equally effective in aiding the plants to survive on the infested soil. Calcium nitrate at 300 pounds per acre was not as effective as the other carriers of nitrogen. Reducing the rate of calcium nitrate to 150 pounds greatly diminished its effectiveness and a 75 pound rate was of practically no value. Heavy superphosphate treatments stimulated early growth on infested soil, but the plants died just as soon as they did on the soil not treated. The soils are naturally alkaline,[4] but the diseased condition is evidently not the direct result of the alkaline reaction since sulfur and sulfuric acid treatments had no beneficial effect. After the third heavy application of sulfur, the soil condition became so unfavorable for growth that the plants died when only about one-half inch in height.

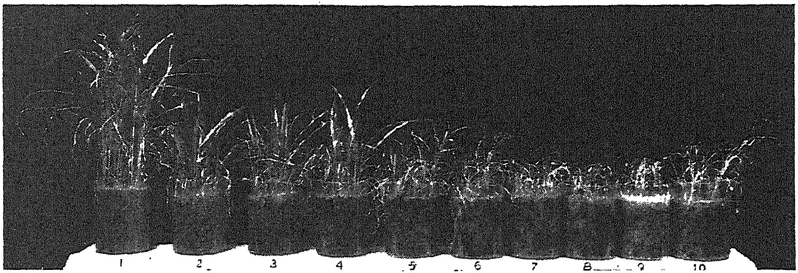

FIG. 1.—The effect of soil treatment on the root, crown, and shoot rot of milo. 1, Non-disease-producing soil; 2 to 10, disease-producing soil plus (2) ammonium nitrate; (3) sodium nitrate; (4) ammonium sulfate; (5) calcium nitrate, 300 pounds per acre; (6) calcium nitrate, 150 pounds and 16% superphosphate, 150 pounds per acre; (7) calcium nitrate, 75 pounds and potassium chloride, 150 pounds per acre; (8) no treatment; (9) sulfur 2,000 pounds per acre; and (10) 16% superphosphate, 1,500 pounds per acre.

SUMMARY

This study indicates that nitrogen when applied at a fairly heavy rate aids in prolonging the life of milo plants grown on soil infested with the organism of the root, crown, and shoot rot of milo. However, nitrogen is not fully effective in overcoming the pathological condition. This suggests that the causitive organism may influence the nitrogen nutrition of the plant.

No other soil treatment tried prolonged the life of the milo plants. The diseased condition of the plant is not caused directly by an alkaline soil reaction.

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[4] ELLIOT, *et al. Loc. cit.*

THE INFLUENCE OF SOIL TREATMENT UPON THE COMPOSITION OF SWEET CLOVER[1]

H. J. SNIDER AND M. A. HEIN[2]

There has been much experimental work reported showing results with sweet clover as a legume for use in soil improvement. Considerable data were reported by Willard[3] upon the composition of sweet clover at various stages of growth. Others have contributed to this and other phases of sweet clover investigation.

The present study was begun with a view to determine the influence of certain soil treatments upon the content of dry matter, nitrogen, phosphorus, and potassium of roots and tops of common sweet clover (*Melilotus alba*) at various stages of its development.

DESCRIPTION OF THE FIELD

A series of fertility plats on the DuBois experiment field, one of the University of Illinois fields in the southern part of the state, was selected for this work. This land had been used as a soil experiment field for 22 years previously. The soil type is designated as Cisne silt loam, a type of large extent in southern Illinois and characterized by having an extremely tight subsoil which makes it wet in the spring and droughty in summer. It is also highly acid in reaction. A detailed description of the experimental work on the field is given by Bauer, *et al.*[4]

A lime treatment consisting of an application of 5 tons an acre of hydrated lime was given at the beginning of the experiment and 2 tons of limestone were applied approximately 20 years later. The reaction of the surface soil on the limed plats varied from pH 6.52 to 6.86. The unlimed soil has a reaction of pH 5.10.

Steamed bone meal had been applied at more or less regular intervals to certain plats, until during the course of 20 years, 4,600 pounds an acre had been put on. The equivalent of 2,300 pounds an acre of potassium sulfate was applied to certain plats. The residues from crops grown on the plats consisting of cornstalks, wheat and oat straw, and clover chaff were returned to the soil as the respective crops appeared in the rotation.

The sweet clover used in these observations was seeded in winter wheat in February. The collection of samples of roots and tops was begun in August and continued at intervals for approximately 1 year.

SAMPLING METHODS

These experimental plats were 1/10 acre in size. The sweet clover roots were removed to the full depth of their penetration of the soil,

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[1] Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication March 6, 1934.

[2] Assistant Chief, Soil Experiment Fields, and formerly Assistant, Soil Experiment Fields, now Bureau Plant Industry, U. S. Dept. Agriculture, respectively.

[3] WILLARD, C. J. When should sweet clover be plowed down? Ohio Agr. Exp. Sta. Bimonthly Bul. 10: 42–44. 1925.

———An experimental study of sweet clover. Ohio Agr. Exp. Sta. Bul. 405. 1927.

[4] BAUER, F. C., SMITH, R. S., and SMITH, L. H. The Illinois soil experiment fields. Ill. Agr. Exp. Sta. Bul. 273. 1926.

which as a rule, did not exceed 12 inches. The tops as well as the roots represented the season's growth at the respective dates of sampling. The dry weights given in Table 1 were based upon the amounts of sweet clover harvested from sampling areas of 4 square feet. The weights recorded under the June 25 date represent the averages of four squares per plat, those under May 15 are averages of two squares per plat, and the remainder are calculated from the weight of a single square. This stand of sweet clover was very uniform over the entire series of plats.

DRY MATTER RESULTS

A comparison of four plats in Table 1 receiving lime (L); lime and phosphorus (LP); lime and potassium (LK); and residues, lime, and phosphorus (RLP), shows that the two plats which received phosphorus produced the heavier growth of roots and tops during the earlier dates in the spring. This difference was overcome to a considerable extent later in the season, although on July 21 the phosphated plats had produced somewhat larger amounts of dry matter than those without phosphate.

TABLE 1.—*Dry matter in sweet clover at different dates, pounds per acre.*

	Aug. 22	Nov. 21	Apr. 4	Apr. 25	May 15	June 25	July 21
Lime							
Tops.......	170	370	—*	530	1,490	5,640	6,290
Roots......	50	690	410	480	630	1,460	1,270
Total.......	220	1,060	410	1,010	2,120	7,100	7,560
Lime and Phosphorus							
Tops.......	200	590	—*	1,460	3,020	5,630	6,550
Roots......	90	900	975	530	1,370	1,490	1,390
Total......	290	1,490	975	1,990	4,390	7,120	7,940
Lime and Potassium							
Tops.......	140	340	—*	770	2,730	5,280	6,220
Roots......	60	710	420	550	900	1,920	1,340
Total......	200	1,050	420	1,320	3,630	7,200	7,560
Residues, Lime, and Phosphorus							
Tops.......	190	510	—*	860	3,400	5,560	6,740
Roots......	70	620	820	600	1,040	1,270	1,230
Total......	260	1,130	820	1,460	4,440	6,830	7,970
Residues, Lime, Phosphorus, and Potassium							
Tops.......	350	940	—*	1,490	4,200	10,150	10,270
Roots......	110	1,540	1,150	1,080	1,580	2,280	1,850
Total.......	460	2,480	1,150	2,570	5,780	12,430	12,150

*No new top growth on April 4.

The soil treatment consisting of residues, lime, phosphorus, and potassium (RLPK) maintained the largest amount of dry matter. The larger amount of organic matter attained under this treatment coincides, with a single exception with the larger amounts of nitrogen, phosphorus, and potassium found in the crop as shown in Tables 2, 3, and 4.

TABLE 2.—*Nitrogen in sweet clover at different dates, pounds per acre.*

	Aug. 22	Nov. 21	Apr. 4	Apr. 25	May 15	June 25	July 21
			Lime				
Tops	5.7	7.1	—*	16.4	43.8	75.6	95.6
Roots	4.6	19.2	15.6	8.9	9.5	14.8	10.7
Total	10.3	26.3	15.6	25.3	53.3	90.4	106.3
			Lime and Phosphorus				
Tops	6.5	12.1	—*	58.2	93.6	105.8	103.5
Roots	2.0	31.0	42.9	12.7	26.7	25.8	19.2
Total	8.5	43.1	42.9	70.9	120.3	131.6	122.7
			Lime and Potassium				
Tops	4.1	6.5	—*	25.7	72.3	78.7	118.2
Roots	1.3	22.7	16.0	11.8	13.0	19.8	11.4
Total	5.4	29.2	16.0	37.5	85.3	98.5	129.6
			Residues, Lime, and Phosphorus				
Tops	5.9	8.7	—*	32.1	101.3	96.2	114.6
Roots	1.4	21.6	37.0	12.8	16.6	15.6	14.0
Total	7.3	30.3	37.0	44.9	117.9	111.8	128.6
			Residues, Lime, Phosphorus, and Potassium				
Tops	11.4	16.0	—*	58.1	119.3	95.4	142.8
Roots	2.6	51.0	50.6	26.8	28.4	32.1	20.3
Total	14.0	66.0	50.6	84.9	147.7	127.5	163.1

*No new top growth on April 4.

TABLE 3.—*Phosphorus in sweet clover at different dates, pounds per acre.*

	Aug. 22	Nov. 21	Apr. 4	Apr. 25	May 15	June 25	July 21
			Lime				
Tops	0.34	0.28	—*	0.94	2.01	4.79	5.97
Roots	0.11	1.90	1.02	0.55	0.66	0.88	0.57
Total	0.45	2.18	1.02	1.49	2.67	5.67	6.54
			Lime and Phosphorus				
Tops	0.75	0.44	—*	5.07	12.38	13.79	13.89
Roots	0.38	3.82	5.36	2.25	4.72	4.17	3.50
Total	1.13	4.26	5.36	7.32	17.10	17.96	17.39
			Lime and Potassium				
Tops	0.28	0.25	—*	1.35	3.68	5.02	5.91
Roots	—†	—†	0.99	0.59	0.76	0.90	0.54
Total	—	—	0.99	1.94	4.44	5.92	6.45
			Residues, Lime, and Phosphorus				
Tops	0.67	0.76	—*	3.42	12.99	13.40	14.15
Roots	0.30	—†	5.12	2.73	3.90	3.45	3.34
Total	0.97	—	5.12	6.15	16.89	16.85	17.49
			Residues, Lime, Phosphorus, and Potassium				
Tops	1.05	0.70	—*	4.99	17.01	18.98	12.84
Roots	0.50	8.47	6.04	3.86	4.98	4.38	1.98
Total	1.55	9.17	6.04	8.85	21.99	23.36	14.81

*No new top growth on April 4.
†Samples exhausted.

RESULTS FROM NITROGEN TREATMENT

The maximum amounts of nitrogen were obtained near the end of the second year growing season. The total amounts of nitrogen (Table 2) contained in the sweet clover July 21 on the various plats varied from 106 pounds to 163 pounds an acre. The gain in nitrogen from April 4 to July 21 varied from 80 pounds to 113 pounds an acre. The plats having the lime and potassium (LK) treatment and the residues, lime, phosphorus, and potassium (RLPK) treatment made practically the same gain.

The lime alone (L) plat carried throughout the season of the second year's growth a smaller amount of nitrogen than did the other plats. The sweet clover on the phosphate-treated plats contained larger total amounts of nitrogen at the earlier dates in the spring than did the unphosphated plats.

RESULTS FROM PHOSPHORUS TREATMENT

The results in Table 3 indicate that the applications of phosphorus to this soil greatly enriched the sweet clover in this element. The maximum total phosphorus found in the sweet clover on the phosphated plats varied from approximately 17 pounds to 23 pounds an acre. On the unphosphated plats the maximum total was approximately 6.5 pounds an acre.

On the RLPK treatment the percentage phosphorus found in the sweet clover tops on May 15, June 25, and July 21 showed a gradual decline for the respective dates as follows: 0.405%, 0.187%, and 0.125%. On the RLP treatment for the same dates, respectively, the decline was as follows: 0.382%, 0.241%, and 0.210%. The decline in the percentage found in the roots was similar to the values for the tops. This more rapid decline in the percentage values on the RLPK treatment accounts largely for the lower value on this plat of pounds per acre of phosphorus on July 21 (Table 3).

The sweet clover on the phosphated plats did not greatly increase in total phosphorus after May 15 (Table 3), while that on the unphosphated plats (L and LK) increased considerably after that date.

RESULTS FOR POTASH TREATMENT

On plats having potash treatment the sweet clover obtained from the soil relatively large quantities of potassium. In Table 4 the average gain from April 4 to July 21 was approximately 29 pounds an acre of potassium on plats without potash treatment. Within the same period the average maximum gain was approximately 80 pounds an acre of potassium on potash-treated plats.

The plat treated with residues, lime, phosphorus, and potassium (RLPK) carried in the sweet clover larger total amounts of potassium than did the plat treated with only lime and potassium (LK).

RATIOS OF AMOUNTS OF MATERIALS IN ROOTS AND TOPS

In Table 5 the dry matter in the sweet clover tops on August 22 exceeded that in the roots by a ratio of 1:2.76. This condition was somewhat reversed on November 21 by a ratio of 1:0.62. During the following April the top growth assumed the lead over the root growth and by July 21 there was a root to top ratio of 1:5.09.

The ratios of nitrogen in roots and tops followed the same general variations as those of the dry matter except during the spring and summer periods the root-top ratios for nitrogen were much wider than those for dry matter.

TABLE 4.—*Potassium in sweet clover at different dates, pounds per acre.*

	Aug. 22	Nov. 21	Apr. 4	Apr. 25	May 15	June 25	July 21
Lime							
Tops	0.55	1.74	—*	4.83	13.39	29.38	29.50
Roots	0.10	3.06	1.85	1.32	1.56	1.34	0.83
Total	0.65	4.80	1.85	6.15	14.95	30.72	30.33
Lime and Phosphorus							
Tops	0.70	1.23	—*	12.56	19.69	24.94	29.87
Roots	0.15	3.75	3.94	1.31	1.60	1.37	0.90
Total	0.85	4.98	3.94	13.87	21.29	26.31	30.77
Lime and Potassium							
Tops	0.87	2.44	—*	11.94	41.63	58.50	52.68
Roots	—	—	1.42	3.80	5.87	7.00	4.53
Total	—	—	1.42	15.74	47.50	65.50	57.21
Residues, Lime, and Phosphorus							
Tops	0.85	1.99	—*	10.20	27.03	30.41	34.24
Roots	0.12	—	4.38	2.42	2.51	1.98	1.76
Total	0.97	—	4.38	12.62	29.60	32.39	36.00
Residues, Lime, Phosphorus, and Potassium							
Tops	2.24	4.78	—*	20.59	72.83	9.17	91.71
Roots	0.32	6.42	5.84	3.94	7.41	93.56	2.40
Total	2.56	11.20	5.84	24.53	80.24	120.73	94.11

*No new top growth April 4.

TABLE 5.—*Ratio of amounts of dry matter, nitrogen, phosphorus, and potassium in sweet clover roots and tops at different stages of development.*

Date harvested	Dry matter	Nitrogen	Phosphorus	Potassium
Aug. 22	1: 2.76	1: 2.82	1: 2.17	1: 6.28
Nov. 21	1: 0.62	1: 0.34	1: 0.10	1: 0.58
Apr. 4	1: 0.00*	1: 0.00	1: 0.00	1: 0.00
Apr. 25	1: 1.57	1: 2.61	1: 1.56	1: 4.70
May 15	1: 2.68	1: 4.56	1: 3.20	1: 9.21
June 25	1: 2.83	1: 4.17	1: 4.06	1: 15.89
July 21	1: 5.09	1: 7.60	1: 5.31	1: 22.84

*New top growth on April 4.

The phosphorus ratios show variations which coincide in a general way with those of nitrogen and organic matter.

The potassium ratios were relatively very wide. The April 25 root-top potassium ratio was 1:4.70, increasing up to 1:22.84 on July 21, indicating that during the growth periods the sweet clover carried the preponderance of its potassium in the tops.

The composition of sweet clover at different dates has an important bearing upon the practice of utilizing it for green manuring, especially during the spring and summer seasons. On the type of soil represented by the DuBois experiment field sweet clover grown for the purpose of obtaining the maximum amounts of organic matter, nitrogen, phosphorus, and potassium, it would seem advisable to allow it to grow to near maturity before utilizing it as green manure. The greater amounts of dry matter, nitrogen, phosphorus, and potassium were contained in sweet clover as it approached maturity between June 25 and July 21. To obtain these maximum amounts would necessitate leaving the sweet clover as the sole crop on the land for a full year or more.

SUMMARY

A study of the composition at different stages of development of sweet clover grown on the DuBois soil experiment field in southern Illinois has brought out the following points:

1. Sweet clover with a soil-treatment consisting of the combination of residues, lime, phosphorus, and potassium contained throughout the season the greater weights per acre of dry matter, nitrogen, and potassium and was below the other treatments in total amount of phosphorus upon only a single date.

2. The total nitrogen contained in the sweet clover varied from 106 pounds an acre on the lime alone plat to 163 pounds on the residues, lime, phosphorus, potassium treatment.

3. The phosphorus treatment increased the total amount per acre of phosphorus from approximately 6.5 pounds on the unphosphated plats to a maximum of approximately 20 pounds on the phosphated plats.

4. The use of potash salts as a soil treatment increased the maximum amount per acre of potassium to 102 pounds as compared to approximately 30 pounds an acre in the sweet clover without potash treatment.

5. The ratio of roots to tops indicates that the sweet clover plant concentrates dry matter, nitrogen, phosphorus, and potassium in the roots during the fall and rapidly translocates these to the tops as growth progresses in the early spring.

6. The maximum amounts of dry matter, nitrogen, phosphorus, and potassium were found in the second year's growth of sweet clover from June 25 to July 21.

RELATIVE NUMBERS OF THREE SPECIES OF RHIZOBIUM IN DUNKIRK SILTY CLAY SOIL[1]

J. K. WILSON[2]

A previous study of the numbers of two species of Rhizobium found in Dunkirk silty clay loam soil from October to June showed that the ratio of the clover nodule bacteria (*Rhizobium trifolii*) to the pea nodule bacteria (*Rh. leguminosarum*) varied between 1.3:1 and 5:1 at various times throughout this period. A further study of the relative numbers of these two species present in samples of soil from four soil types showed that these types also supported a larger number of *Rh. trifolii* than of *Rh. leguminosarum*. From such data it was concluded that soils vary in their capacity to maintain these two species of the root nodule bacteria. The present report represents a continuation of that study and presents data on the relative numbers of the above two species and of the soybean nodule bacteria (*Rh. japonicum*) which were found in samples of Dunkirk silty clay loam soil.

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[1] Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication March 8, 1934.

[2] Professor of Soil Technology.

The methods used in this study were essentially the same as those used in the previous studies.[3] There were some slight modifications. The samples were taken from only 1 location instead of 10. The sterile sandy soil in the tumblers on which the dilutions were placed was made more suitable for plant and bacterial growth, and also for increased nodulation[4] by wetting with a solution containing about 0.01% K_2HPO_4 and 0.05% of sucrose just before the dilutions were added, instead of with distilled water. Also, since it was desirable to ascertain the numbers of the above-named three species of Rhizobium not only in the same sample of soil but also in the same fraction of a gram, seeds of the host plants of the three bacterial species, treated to remove surface contamination, were planted together in the same tumbler in which the fraction of a gram of the soil was added.

During the week of June 17 to 24, 1933, samples were collected for bacterial analysis from plats on Dunkirk silty clay loam soil. Well-nodulated soybeans have grown on these plats; in some cases as recently as 1932 and in another case 25 years had passed since this plant was grown on the plat. Red clover had been grown either as a crop in recent years on the plats or volunteer plants had appeared on them nearly every year. No accurate information is available as to how recently, if ever, a member of the Pisum cross inoculation group has grown on the plats. All of the plats, however, have been exposed by farming operations to contamination with *Rh. leguminosarum*. This should have permitted the soil to be well stocked with this organism. On some of the plats peas were growing when the samples were collected. All of the samples were examined for the numbers of the root nodule bacteria representing the three species listed above. Such information as might be helpful in drawing conclusions from the findings was also taken. The results of this supplementary study are presented in Table 1.

In 52 of the 55 cases the numbers of *Rh. trifolii* in the samples of soil were larger than the numbers of *Rh. leguminosarum*. In two instances the numbers of these two organisms were approximately the same and in one instance the number of *Rh. leguminosarum* was larger than that of *Rh. trifolii*. Probably of greater importance is the fact that by the methods used 16 of the samples failed to show the presence of *Rh. leguminosarum* in as much as 300 grams of the soil, and that 34 of the 55 samples contained only 100 or less of the organisms in a gram of soil. It is pointed out also that 47 of the 55 samples contained 25,000 or more *Rh. trifolii* in a gram of the soil. The ratio of this latter organism to *Rh. leguminosarum* was about 71:1. These data substantiate those reported in previous papers.[5]

Apparently none of the samples contained as many as 1,000 *Rh. japonicum* in a gram of the soil. In only 5 of the 55 samples were

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[3] WILSON, J. K. Seasonal variation in the number of two species of Rhizobium in soil. Soil Science, 30 : 289–296. 1930.

————. Relative numbers of two species of Rhizobium in soils, Jour. Agr. Res., 43 : 261–266. 1931.

[4] WILSON, J. K. Physiological studies of *Bacillus radicicola* of the soybean (*Soja Max* Piper) and of the factors influencing nodule production. Cornell Agr. Exp. Sta. Bul. 386 : 369–413. 1917.

[5] See footnote 3.

TABLE 1.—*The relative numbers of three species of Rhizobium in Dunkirk silty clay loam soil, June 17 to 23, 1933.*

Plat No.	1933 crop	Moisture in sample %	pH	Number per gram of		
				Rh. trifolii	*Rh. leguminosarum*	*Rh. japonicum*
3638	Timothy	25	5.0	500,000	—*	500
2235	Grass	25	7.6	250,000	100	—*
3814	Grass	25	6.1	100,000	500	—*
7011S	Rye and vetch	25	7.3	250,000	250,000	—*
7005S	Wheat	25	5.2	25,000	50,000	100
7205	Wheat and rye	25	5.4	10,000	100	—*
7211	Wheat and rye	25	7.3	250,000	—†	—*
7533	Oats	25	5.7	100,000	500	—*
R7	Grass	25	5.8	1,000,000	100,000	100
R5	Grass	25	5.5	500,000	10,000	100
R4	Grass	25	6.9	1,000,000	10,000	—*
R5	Grass	25	5.6	100,000	25,000	100
R17	Alfalfa	10	7.3	250,000	—*	—*
7420	Corn	25	5.6	50,000	10,000	100
R15	Alfalfa	10	6.5	250,000	—*	—†
R12	Alfalfa	8	6.6	10,000	—*	—*
R13	Wild mustard	8	7.4	25,000	—*	—†
R19	Clovers	12	5.9	500,000	5,000	—†
F68S	Bare	10	8.2	25,000	—†	100
7001	Clover	25	5.3	1,000,000	—*	—*
7002	Clover	25	5.3	1,000,000	—*	100
7003	Clover	25	5.3	1,000,000	—*	100
7004	Wheat	25	5.3	1,000,000	—*	—*
7005	Wheat	25	5.2	1,000,000	—†	—*
7006	Wheat	25	5.2	1,000,000	—†	—*
7007	Bare	25	5.0	500,000	—*	500
7008	Bare	25	5.7	250,000	100	100
7009	Bare	25	7.0	100,000	—†	—*
7010	Wheat	25	7.5	250,000	500	500
7011	Wheat and vetch	25	6.0	1,000,000	500	100
7012	Rye and vetch	25	7.5	250,000	500	100
7013	Rye	25	7.0	25,000	100	—†
7014	Timothy	25	5.6	500	100	—*
7015	Vetch	25	6.5	500,000	1,000	—†
7016	Bare	25	5.3	500	100	—*
7403	Peas	25	5.8	10,000	10,000	—*
R10	Timothy	8	6.5	500,000	—†	—†
R16	Corn	10	5.8	250,000	—*	—*
R18	Barley	12	5.9	50,000	—*	—*
R20	Clovers	12	6.4	500,000	100	—†
F68N	Bare	10	8.2	100,000	—*	—*
F56N	Rye	10	8.2	25,000	—†	500
752E	Wheat	25	7.6	50,000	25,000	100
755E	Wheat	25	5.1	100	—†	—*
7018	Bare	25	5.9	50,000	500	—*
R11	Oats	8	7.0	100,000	—*	—*
R14	Clovers	12	6.6	250,000	100	100
7405	Peas	25	5.9	25,000	10,000	—†
F56S	Rye	10	8.2	250,000	—*	500
7028	Bare	25	6.1	250,000	100	100
R6	Grass	25	7.6	1,000,000	25,000	—*
761A	Wheat	25	5.0	100	—*	—†
758A	Wheat	25	7.6	25,000	10,000	—*
7012S	Rye and vetch	25	5.7	1,000	100	—*
7015S	Bare	25	6.4	250,000	10,000	—†

*No nodules formed on plants grown in about 300 gr. of the soil.
†Nodules formed on plants grown in about 300 gr. of the soil.

there 500 in a gram. In 10 of the samples the organism was not present in 1/100 gram. They were present, however, to some extent in about 300 grams of the soil. This was determined by nodule production on plants when they were grown in the original soil. In 26 of the samples the organism was absent from 300 grams of the soil when the same criterion of its presence was used. In every sample the numbers of *Rh. japonicum* were smaller than the numbers of *Rh. trifolii.* In 45 of the 55 samples the numbers of *Rh. japonicum* were smaller than the numbers of *Rh. leguminosarum.*

It seems fair to say from the data presented that in Dunkirk silty clay loam one may expect to find the numbers of *Rh. trifolii*, *Rh. leguminosarum*, and *Rh. japonicum* in a rather definite numerical order. They seem to be present in the soil in the order listed above. When the 55 samples which were examined are considered there are for every 5,830 *Rh. trifolii* about 82 *Rh. leguminosarum* and 1 *Rh. japonicum.*

DISCUSSION

The data presented in this paper substantiate and extend the thesis that soils vary in their capacity to maintain various species of the root nodule bacteria. As previously pointed out, neither the acidity nor the alkalinity of the soil appears to have had anything to do with this relationship. No significance can be attached to the moisture content of the soil, to the season of the year when the samples were taken, or to the crop on the soil as bearing any relation to the findings. No direct data are available to explain why soils vary in their capacity to support the various species of the root nodule bacteria. It might be pointed out that this numerical relationship coincides very closely with the hardiness of these three species when they are grown on an artificial medium in the laboratory, and also with the hardiness of the three host plants when they are grown in the field.

EFFECT OF VARIOUS SMUT TREATMENTS ON YIELD OF WINTER WHEAT[1]

A. F. BRACKEN[2]

Under certain conditions, formalin will reduce the vitality of the seed when used to control smut of wheat. Copper sulfate is also harmful, but not to the same extent as formalin. Since both of these disinfectants may reduce the germination percentage of seed grain, it is likely that the effect may reflect itself in yield, either by an actual reduction in stand or by diminishing the vigor of the surviving plants. The investigation herein reported was undertaken with a view to determine the effect of formalin, copper sulfate, and copper carbonate on yields of fall wheat as compared to sowing untreated seed under dry-land conditions in Utah.

[1] Contribution from Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Also presented before the A. A. A. S., Berkeley, Calif., June, 1934. Publication authorized by the Director March 5, 1934. Received for publication March 8, 1934.

[2] Superintendent, Nephi Dry-land Substation, Nephi, Utah.

METHOD OF CONDUCTING EXPERIMENT

This experiment was conducted at the Nephi Dry-Land Substation located in central Utah. The average yearly fall of precipitation totals 13.05 inches, two-thirds of this amount coming during the fall, winter, and early spring months. The plats on which the test was conducted were 1/20 acre in size. Each treatment was replicated three times. The rate of sowing was 6 pecks to an acre. For the copper sulfate and formaldehyde treatments, the seed was soaked in these solutions for a period of 10 minutes, allowed to drain, and drilled about 6 hours later. Standard formaldehyde diluted to the equivalent of 1 pint to 40 gallons of water was used as one of the disinfecting solutions. For copper sulfate, 1 pound was dissolved in 5 gallons of water. Since dry farmers in Utah seldom use lime, this treatment was not given subsequently after soaking in the copper sulfate solution. The copper carbonate used contained 18% metallic copper. Because of previous care in preventing infection, the untreated seed was almost smut-free.

EXPERIMENTAL RESULTS

As indicated by Table 1, this experiment was conducted for a 10-year period (1924–33, inclusive), which is sufficiently long enough to include most of the climatic variations affecting the germination of fall-sown winter wheat. The average acre yields covering this period showed 24.7 bushels for untreated wheat, 24.8 bushels for wheat treated with copper carbonate, 23.4 bushels where a solution of copper sulfate was used, and 21.8 bushels for the formalin-treated wheat. Analyzing the data by Fisher's variance method to determine the significance of the results, it was found that with a value of .05 for P, the standard deviation of the difference amounted to 1.37 bushels and 1.88 bushels, when P equaled .01. Variance due to season, soil, and seed treatment was eliminated from the total. The calculations were made on the basis of the random variance over the entire 10-year period. Using these figures for determining the reliability of the results, it is apparent that the differences of 1.6 bushels between copper sulfate and formalin and of 1.4 bushels between copper sulfate and copper carbonate are significant. When comparison is made between formalin and copper carbonate, with a difference of 3 bushels for the latter, it is apparent that the odds are extremely high, favoring the use of copper carbonate. Heald, *et al.* (1),[3] Ross (2), Leukel (3), and Selvig (4), in tests covering short periods of time, likewise claimed that formalin depressed the yield of wheat as compared to copper carbonate, the latter measuring a difference of 3.6 bushels. Richardson (5) observed the same relationship and, in addition, found that copper sulfate reduced the vitality of the grain.

In examining the yearly average for the various treatments, as given in Table 1, it will be observed that no appreciable differences in yield occurred between seed treatments for 1925, 1927, 1929, and 1931. In only one of these seasons, 1931, was there sufficient moisture to force germination in a relatively short time after drilling.

[3] Figures in parenthesis refer to "Literature Cited," p. 751.

In 1925 the grain emerged 35 days after seeding, and in 1927 and 1929 the soil remained dry until winter began, with the wheat germinating under the snow. Of the remaining six seasons showing differences with varying degrees of significance, the wheat emerged in the fall of 1924, 1926, and 1933. For the years of 1928, 1930, and 1932 the seed remained ungerminated until sometime during the winter or early spring. For 1926, however, the plants were up 12 days after drilling, and yet the wet treatments somewhat reduced the yield. Wherever the formaldehyde treatment reduced the yield, it is observed that copper sulfate did likewise with the exception of 1930. However, copper sulfate was only intermediate in its damage.

For those seasons in which the wet treatments lowered yields, the decreased production was due mainly to a reduced stand of plants and partly to a lack of plant vigor. With formalin this was more accentuated than indicated by the yields. Even in the crop season of 1927, 1929, and 1931, with no difference between treatments in respect to yield, there was a noticeable delay in growth of grain treated with formalin. In most all cases, however, as the season advanced, the differences became less pronounced. Upon examination of the plants in the various plats, injury due to use of formaldehyde showed a noticeable retardation of germination and, in some cases, curving of the plumule. This was observed by Hurd (6) in her work on formalin damage. It was also observed that the coleoptile broke open a short distance after emerging through the testa, leaving the spindly, weak leaves without protection and unable to push through the soil to the surface. This type of injury was especially noticeable for the seasons of 1932 and 1933. Damage of this sort becomes rather severe when the young plants encounter a crusted condition of the surface soil. Comparing the damage from use of copper sulfate and of formalin, it was observed that for copper sulfate the injury was uniform for all plats, but for formalin the killing occurred over rather irregular areas, giving the stands a patchy appearance.

It is thus apparent from the yields, as given in Table 1, that winter wheat treated with formalin or copper sulfate may be seeded in soil too dry to force immediate germination and yet not suffer damage. On the other hand, it is obvious that the chances are greater that damage will occur, especially when formalin is used as the disinfectant. Under natural conditions in the field, it is difficult to determine the factors responsible for this variation. As Hurd (6) observed with formalin, it may be a question of humidity. She found that in atmospheres of more than 70% humidity seed could be kept indefinitely without ill effects. With 70% humidity, and less, there was decided injury, which became most severe in the intermediate humidities, gradually decreasing until seed stored in an absolutely dry chamber was almost uninjured. If the humidity of the soil air were measured in seasons which were so dry as to prevent germination of the grain, it is quite likely variations would be found, which might account for a part of the difference in results, in spite of the fact that outwardly the soil condition may appear to be the same.

An examination of the average yields of wheat treated with copper carbonate and of wheat receiving no treatment for control of smut, as given in Table 1, indicates that the yields are almost identical. No smutted heads were observed in the untreated wheat; however, it is apparent that if smut had occurred, the yield would have shown a reduction almost in proportion to the percentage of infection.

TABLE 1.—*Effect of various seed treatments for smut on yield of winter wheat with date of seeding and date of emergence, 1924–33, inclusive.*

	Year										
Treatment	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	Av.
No treatment.....	22.5	42.1	37.0	17.3	29.9	21.2	24.1	18.6	14.6	19.4	24.7
Copper carbonate ...	23.7	40.2	36.3	17.5	29.3	19.3	25.8	21.3	15.1	19.6	24.8
Copper sulfate......	19.6	40.7	33.2	17.3	27.5	19.2	26.7	19.0	13.5	17.7	23.4
Formalin...	20.2	39.5	34.2	17.6	26.2	19.4	20.9	20.1	10.6	9.8	21.8
Date seeded.	Sept. 25	Sept. 20	Sept. 20	Sept. 18	Sept. 19	Oct. 5	Sept. 22	Oct. 15	Sept. 18	Oct. 9	—
Date of emergence.....	Oct. 20	Oct. 25	Oct. 2	W*	W	W	W	Oct. 27	W	Nov. 18	—

*W = Winter.
Significant difference with P = .05–1.37 bu.
Significant difference with P = .01–1.88 bu.

SUMMARY

In a yield test of winter wheat covering a 10-year period to determine the effect of various seed treatments, it was found that untreated seed gave an average acre yield of 24.7 bushels, copper carbonate 24.8 bushels, copper sulfate 23.4 bushels, and formalin-treated wheat 21.8 bushels. A statistical analysis of the results showed that all of the differences were significant.

Fall seeding in dry soil, in the majority of cases, was associated with a lowering of the yield for the wet treatments. In spite of this fact, however, in two seasons out of the four where no difference of yield was shown in regard to treatment, the seed failed to emerge until winter or early spring.

LITERATURE CITED

1. HEALD, F. D., ZUNDEL, G. L., and BOYLE, L. W. Dusting of wheat and oats for smut. Phytopath., 13 : 169–183. 1922.
2. ROSS, H. Experiments for the control of bunt. Agr. Gaz. New South Wales, 34 : 780. 1923.
3. LEUKEL, R. W. Further experiments on control of bunt of wheat. Phytopath., 16 : 347–351. 1925.
4. SELVIG, C. G. Smut treatment tests. Minn. Sta. Crookston Substa. Rpt.: 43–44. 1923.
5. RICHARDSON, A. E. V. Treatment of wheat for smut. Dept. Agr. Jour Victoria, 22 : 224–230. 1924.
6. HURD, ANNIE MAY. Injury to seed wheat resulting from drying after disinfection with formaldehyde. Jour. Agr. Res., 20 : 209–244. 1920.

RECLAMATION OF VIRGIN BLACK ALKALI SOILS[1]

J. L. WURSTEN AND W. L. POWERS[2]

Black alkali land reclamation experiments were centered at Vale, Oregon, in 1920. The alkali experiment field there is the oldest in northwestern United States and affords perhaps the first example of the reclamation of hard virgin black alkali land or solnetz. The alkaline soil at the experimental field near Fresno, California, appears to be solonchak and was previously cropped. Early history of these investigations was reported by Johnston and Powers (6)[3] and a later progress report given by Powers (9). The experiment field was virgin black alkali land with hard subsoil and initial pH of 10.0 to 10.5.

Deep drainage, clearing, and leveling and different chemical treatments have been employed at Vale. Chemicals were fallowed in so that reaction could occur before leaching. Following a period of leaching, rye was established with certain treatments. This was used as a nurse crop for sweet clover and alfalfa. Sweet clover has generally been used as green manure in preparation for alfalfa. The check plats are treated in every way like other plats, except for the chemical treatments. There has been a gradual increase in the amount of stand on treated plats until yields of recent crops on certain plats have equalled those on normal fertile soil in the locality. The object of the present study is to learn the extent of removal of adsorbed sodium and of soluble salts and the effect upon the crop-producing powers of the soils involved.

Sulfur was perhaps first used on alkali soil by the Oregon Agricultural Experiment Station near Klamath Falls, Oregon, in 1917 and its value reported in 1920 (10). In connection with his work on sulfur, Lipman (8) had suggested that sulfur might be effective in decomposing sodium carbonate in soils. Hilgard (5) earlier suggested the use of gypsum in proportion to concentration of alkali to be neutralized and experiments of Gedroiz (3), Kelley (7), and deSigmond (4) included the gypsum treatment to effect substitution of calcium for exchange of sodium in alkali soil. Scofield (12) emphasized the need of flocculents, such as alum, to improve percolation so that salts could be leached out of alkali soil. At the Arizona Station (1) the value of carbon-dioxide in improving alkali soil has been emphasized. Treatments to increase organic matter in Vale soils have been included in these trials from the time of their initiation.

EXPERIMENTAL WORK

Samples were drawn in the fall of 1932 from the original plats of the Vale experiment field by layers 0–5, 5–20, and 20–40 inches in depth as previously done periodically. Determinations of base exchange were made by the two-tube method as proposed by Burgess and

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[2] Graduate Assistant and Soil Scientist, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 762.

Breazeale (2). Organic matter was determined by the modified Rather method (11). Other determinations were by standard methods.

EXCHANGEABLE BASES IN ALKALI EXPERIMENT PLATS

The amount and kind of adsorbed bases is of first importance in indicating the extent of alkalinity or progress of reclamation. Exchange calcium and sodium are reported in Table 1 in M.E. per 100 grams of soil; also in percentage of base capacity. Solubility effect was corrected by leaching a second litter and determining the calcium therein. Necessary corrections for soluble salts were made. Negligible amounts of potassium and magnesium were found. The soil was practically saturated with calcium and sodium and their sum was taken as base capacity.

The soil from chemically treated plats is now largely calcium saturated, while check plats are still mostly saturated with sodium as they were in the virgin state according to initial data at the foot of Table 1. This exchange of sodium for calcium is largely accomplished as manifested throughout the 40-inch profile though more advanced in the surface 20 inches. The soil samples show good base exchange capacity which tends to be higher in the subsoil. The exchange of calcium for sodium is most nearly complete in plats receiving sulfur and manure. Elimination of sodium is well advanced where sulfur and gypsum were used together. It is about one-half completed where green manure was added. Gypsum alone has been less effective.

WATER SOLUBLE SALTS

The amounts of salts in different plat profile layers are presented in Table 2. The initial salt content of the first 5 feet of soil is from 8 to 15 tons per acre foot according to the data at the base of Table 2. The total salts is taken as the sum of the carbonate, bicarbonate, sulfate, and chloride. In every case there is a marked difference between the check and the treated plat. Checks contain 2 to 4 times more salt. Improved permeability of treated plats and lack of vegetative cover on checks is regarded as partly responsible for the greater relative concentration of salts near the surface in checks, where there is a marked reduction in treated plats, especially in surface layers. Alkaline carbonates have disappeared in the surface layer of plats A, C, D, F, and H and from the 5- to 20-inch layer on A, C, and H.

In almost every case chlorides are concentrated in the 5- to 20-inch layer while sulfates are mostly in the surface 5 inches. This difference in vertical distribution of these salts is attributed to difference in solubility.

SALTS LOST DURING 11-YEAR PERIOD, 1921–32

The loss in total salts and sodium carbonate to a depth of 40 inches for plats A to L is summarized in Table 3. The relative amount of saline and alkali salts removed from the check plats has been low. Only with chemical treatment is there marked elimination of sodium carbonate.

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J. L. Wursten and W. L. Powers[2]

Black alkali land reclamation experiments were centered at Vale, Oregon, in 1920. The alkali experiment field there is the oldest in northwestern United States and affords perhaps the first example of the reclamation of hard virgin black alkali land or solnetz. The alkaline soil at the experimental field near Fresno, California, appears to be solonchak and was previously cropped. Early history of these investigations was reported by Johnston and Powers (6)[3] and a later progress report given by Powers (9). The experiment field was virgin black alkali land with hard subsoil and initial pH of 10.0 to 10.5.

Deep drainage, clearing, and leveling and different chemical treatments have been employed at Vale. Chemicals were fallowed in so that reaction could occur before leaching. Following a period of leaching, rye was established with certain treatments. This was used as a nurse crop for sweet clover and alfalfa. Sweet clover has generally been used as green manure in preparation for alfalfa. The check plats are treated in every way like other plats, except for the chemical treatments. There has been a gradual increase in the amount of stand on treated plats until yields of recent crops on certain plats have equalled those on normal fertile soil in the locality. The object of the present study is to learn the extent of removal of adsorbed sodium and of soluble salts and the effect upon the crop-producing powers of the soils involved.

Sulfur was perhaps first used on alkali soil by the Oregon Agricultural Experiment Station near Klamath Falls, Oregon, in 1917 and its value reported in 1920 (10). In connection with his work on sulfur, Lipman (8) had suggested that sulfur might be effective in decomposing sodium carbonate in soils. Hilgard (5) earlier suggested the use of gypsum in proportion to concentration of alkali to be neutralized and experiments of Gedroiz (3), Kelley (7), and deSigmond (4) included the gypsum treatment to effect substitution of calcium for exchange of sodium in alkali soil. Scofield (12) emphasized the need of flocculents, such as alum, to improve percolation so that salts could be leached out of alkali soil. At the Arizona Station (1) the value of carbon-dioxide in improving alkali soil has been emphasized. Treatments to increase organic matter in Vale soils have been included in these trials from the time of their initiation.

EXPERIMENTAL WORK

Samples were drawn in the fall of 1932 from the original plats of the Vale experiment field by layers 0–5, 5–20, and 20–40 inches in depth as previously done periodically. Determinations of base exchange were made by the two-tube method as proposed by Burgess and

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[1] Contribution from the Soils Department, Oregon Agricultural Experiment Station, Corvallis, Ore. Published as technical paper No. 202 with the approval of the Director. Received for publication March 28, 1934.

[2] Graduate Assistant and Soil Scientist, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 762.

Breazeale (2). Organic matter was determined by the modified Rather method (11). Other determinations were by standard methods.

EXCHANGEABLE BASES IN ALKALI EXPERIMENT PLATS

The amount and kind of adsorbed bases is of first importance in indicating the extent of alkalinity or progress of reclamation. Exchange calcium and sodium are reported in Table 1 in M.E. per 100 grams of soil; also in percentage of base capacity. Solubility effect was corrected by leaching a second litter and determining the calcium therein. Necessary corrections for soluble salts were made. Negligible amounts of potassium and magnesium were found. The soil was practically saturated with calcium and sodium and their sum was taken as base capacity.

The soil from chemically treated plats is now largely calcium saturated, while check plats are still mostly saturated with sodium as they were in the virgin state according to initial data at the foot of Table 1. This exchange of sodium for calcium is largely accomplished as manifested throughout the 40-inch profile though more advanced in the surface 20 inches. The soil samples show good base exchange capacity which tends to be higher in the subsoil. The exchange of calcium for sodium is most nearly complete in plats receiving sulfur and manure. Elimination of sodium is well advanced where sulfur and gypsum were used together. It is about one-half completed where green manure was added. Gypsum alone has been less effective.

WATER SOLUBLE SALTS

The amounts of salts in different plat profile layers are presented in Table 2. The initial salt content of the first 5 feet of soil is from 8 to 15 tons per acre foot according to the data at the base of Table 2. The total salts is taken as the sum of the carbonate, bicarbonate, sulfate, and chloride. In every case there is a marked difference between the check and the treated plat. Checks contain 2 to 4 times more salt. Improved permeability of treated plats and lack of vegetative cover on checks is regarded as partly responsible for the greater relative concentration of salts near the surface in checks, where there is a marked reduction in treated plats, especially in surface layers. Alkaline carbonates have disappeared in the surface layer of plats A, C, D, F, and H and from the 5- to 20-inch layer on A, C, and H.

In almost every case chlorides are concentrated in the 5- to 20-inch layer while sulfates are mostly in the surface 5 inches. This difference in vertical distribution of these salts is attributed to difference in solubility.

SALTS LOST DURING 11-YEAR PERIOD, 1921–32

The loss in total salts and sodium carbonate to a depth of 40 inches for plats A to L is summarized in Table 3. The relative amount of saline and alkali salts removed from the check plats has been low. Only with chemical treatment is there marked elimination of sodium carbonate.

TABLE 1.—*Exchangeable bases in Vale alkali experiment plats, sampled fall, 1932.*

Plat and layer	Total treatments received to 1933	Base exchange capacity, M.E. 100 grams	Exchange Ca,* M.E. 100 grams	Exchange Na, M.E. 100 grams	Ca part of exchange capacity %	Na part of exchange capacity %
A 0–5	Manure, 10 tons	19.03	13.32	5.71	70.0	30.0
5–20	6 years 60 tons	21.85	12.46	9.39	57.1	42.9
20–40	Sulfur 1.5 tons	26.15	13.07	13.08	50.0	50.0
B 0–5	Untreated	22.62	4.36	18.26	14.9	85.1
5–20	Untreated	29.30	5.31	23.99	18.1	81.9
20–40	Untreated	30.18	11.84	18.34	39.2	60.8
C 0–5	Manure, 8 tons	19.74	12.90	6.84	65.5	34.5
5–20	5 years, 40 tons	22.72	13.84	8.88	60.9	39.1
20–40	Sulfur, 1,500 lbs.	26.45	11.03	15.42	41.7	58.3
D 0–5	Manure, 8 tons	20.04	11.30	8.74	56.3	43.7
5–20	5 years, 40 tons	24.32	5.58	18.74	23.4	76.6
20–40	Gypsum, 2 tons	27.60	6.13	21.47	22.2	77.8
E 0–5	Untreated	21.40	3.14	18.26	14.6	85.4
5–20	Untreated	25.72	1.92	23.80	7.5	92.5
20–40	Untreated	30.42	7.02	23.40	23.0	77.0
F 0–5	Green manure	21.04	11.35	9.69	53.4	46.6
5–20	3 tons per year	25.58	9.67	15.91	37.8	62.2
20–40	Sulfur, 600 lbs	28.66	8.57	20.09	29.8	70.2
G 0–5	Sulfur, 1.66 tons	21.41	11.31	10.10	52.8	47.2
5–20		26.27	9.30	16.97	35.4	64.6
20–40		29.53	6.54	22.99	22.1	77.9
H 0–5	Sulfur, 2.25 tons	20.16	14.54	5.62	72.2	27.8
5–20	Gypsum, 6.25 tons	30.29	14.99	15.30	49.4	50.6
20–40		29.33	11.02	18.31	37.9	62.1
I 0–5	Untreated	20.25	6.88	13.37	33.9	66.1
5–20	Untreated	32.78	1.96	30.82	6.0	94.0
20–40	Untreated	28.34	1.64	26.70	5.8	94.2
J 0–5	Gypsum, 6.25 tons	21.05	10.13	10.92	48.1	51.9
5–20		32.26	5.58	26.68	17.3	82.7
20–40		32.49	4.09	28.40	12.2	87.8
K 0–5	Gypsum, 6.8 tons	23.51	12.19	11.32	51.8	48.2
5–20		33.20	2.40	30.80	7.2	92.8
20–40		33.37	1.99	31.38	5.9	94.1
L 0–5	Gypsum, 10.2 tons	22.68	12.58	10.10	55.4	44.6
5–20		32.16	3.23	28.93	10.4	89.6
20–40		31.88	2.87	29.01	9.0	91.0
Virgin soil						
0–50		24.94	2.40	22.06	11.6	88.4
5–20		30.94	1.07	29.31	5.3	94.7

*Combined calcium and magnesium, mostly calcium.

TABLE 2.—*Water-soluble salts in Vale alkali experiment plats, sampled fall, 1932.*

Plat and layer	Total treatments received to 1933	Total salts, p.p.m.	Carbonates (CO$_3$), p.p.m.	Bicarbonates (HCO$_3$), p.p.m.	Chlorides (Cl), p.p.m.	Sulfates (SO$_4$), p.p.m.
A 0–5	Manure, 10 tons	836	0	281	72	483
5–20	For 6 years 60 tons	958	Trace	427	514	17
20–40	Sulfur, 1.5 tons	1,071	90	518	426	37
B 0–5	Untreated	2,780	144	927	90	1,619
5–20	Untreated	2,510	120	915	1,260	215
20–40	Untreated	1,695	60	427	781	427
C 0–5	Manure, 8 tons	553	0	232	36	285
5–20	5 years, 40 tons	858	0	457	355	46
20–40	Sulfur, 1,500 lbs.	1,207	120	579	461	47
D 0–5	Manure, 8 tons	1,111	0	293	72	746
5–20	5 years, 40 tons	1,758	90	732	923	13
20–40	Gypsum, 2 tons.	1,382	120	671	550	41
E 0–5	Untreated	5,962	900	3,806	780	476
5–20	Untreated	3,569	360	1,250	1,597	362
20–40	Untreated	2,076	270	854	834	118
F 0–5	Green manure,	1,522	Trace	366	780	376
5–20	3 tons per year	1,385	60	549	745	31
20–40	Sulfur, 600 lbs.	1,874	240	854	763	17
G 0–5	Sulfur, 1.66 tons	1,503	12	415	607	469
5–20		1,420	90	579	727	24
20–40		1,804	210	732	816	46
H 0–5	Sulfur, 2.25 tons	1,325	0	219	696	410
5–20	Gypsum, 6.25 tons	1,161	Trace	457	692	12
20–40		1,327	150	610	550	17
I 0–5	Untreated	2,070	96	634	589	483
5–20	Untreated	4,355	270	1,433	1,792	860
20–40	Untreated	4,323	720	1,372	1,508	723
J 0–5	Gypsum, 6.25 tons	1,912	84	488	807	533
5–20		2,814	300	1,128	1,366	20
20–40		2,514	360	1,128	958	68
K 0–5	Gypsum, 6.8 tons	1,967	84	512	786	585
5–20		3,698	120	915	1,295	1,368
20–40		3,230	450	854	1,029	897
L 0–5	Gypsum, 10.2 tons	2,048	60	476	696	876
5–20		3,090	180	1,098	1,295	517
20–40		3,450	330	854	940	1,326
Virgin soil						
0–12		7,350	929	—	639	2,776
12–24		7,700	891	—	705	3,694
24–36		5,205	652	—	513	2,414
36–60		4,052	485	—	418	1,894
60–84		1,463	250	—	243	530

TABLE 3.—*Salts lost during 11-year period, 1921–32, to 40-inch depth.*

Plat	Total salts, p.p.m.	Sodium carbonate, p.p.m.
A	5,449	1,057
B	3,308	401
C	10,612	1,636
D	6,251	1,468
E	2,498	1,170
F	7,562	1,790
G	4,811	1,407
H	4,440	617
I	1,154	950
J	5,378	708
K	6,391	1,538
L	3,173	1,181

EFECT OF RECLAMATION ON AVAILABLE NUTRIENTS

Table 4 presents pH, total nitrogen, organic matter, water-soluble phosphate, and water-soluble calcium as determined on plats A to L, inclusive. The results presented are for the respective layers, 0–5, 5–20, and 20–40 inches. It will be noticed that the reaction of the surface soils on some of the better plats is approaching neutrality. There is a distinct increase in pH with depth, also the marked difference in the treated plats and the check plats. The reaction on the more favorably treated plats is now well within the growth range of alfalfa. Plats are low in total nitrogen, but the results show evidence of a gain on the treated plats. In the case of organic matter, the plats receiving manure show a distinct increase over the other plats and all the treated plats show an increase as compared with the check plats. This is due to the fact that the treated plats will grow crops which result in a return of some crop residues to the soil. All the plats contain a large amount of water-soluble phosphorus, so presumably this is not a limiting factor. In the case of phosphorus the check plats and the poorer treated plats contain more than the better plats. This is explained by the fact that phosphorus may be present in the form of sodium phosphate and also by the fact that on the better plats the crops may have removed some phosphorus from the soil. All plats are low in water-soluble calcium and there is no appreciable difference in the amount contained by the treated and check plats. It is interesting to note that in almost every case the largest amount of water-soluble calcium is contained in the 5- to 20-inch layer.

YIELDS OF HAY SECURED ON ALKALI EXPERIMENT PLATS

The yields of hay in pounds per acre obtained with the initial plats of the Vale experiment field receiving different treatments for the most of the past 10 years are presented in Table 5. There is still practically no stand of tame growths on the untreated plats, while plats A and G receiving sulfur with manure, or green manure, have come to have nearly a perfect stand and are producing good yields for the locality. Some seasonal variation is to be noted in yields.

TABLE 4.—*Effect of reclamation on available nutrients.*

Plat and layer	Reaction, pH	Total N, %	Organic matter %	Water-soluble PO_4, p.p.m.	Water-soluble Ca, M.E. to 100 grams
A 0–5	7.8	0.0728	2.35	2.8	0.1375
5–20	8.0	0.0336	1.00	7.1	0.282
20–40	8.7	0.0280	0.80	1.8	0.062
B 0–5	8.8	0.0532	1.33	3.9	0.125
5–20	9.3	0.0280	1.00	6.4	0.099
20–40	8.4	0.0336	1.00	1.1	0.075
C 0–5	7.8	0.0616	2.75	1.4	0.150
5–20	8.2	0.0308	0.87	4.6	0.116
20–40	9.2	0.0280	1.00	2.6	0.062
D 0–5	7.9	0.0692	1.81	1.5	0.125
5–20	8.8	0.0280	1.04	7.8	0.232
20–40	9.2	0.0260	0.92	3.0	0.062
E 0–5	9.2	0.0392	1.49	5.7	0.125
5–20	9.5	0.0224	1.00	9.0	0.216
20–40	8.9	0.0308	1.00	4.0	0.125
F 0–5	8.0	0.0692	1.75	1.8	0.075
5–20	8.6	0.0392	1.10	5.7	0.216
20–40	8.9	0.0270	1.10	4.2	0.075
G 0–5	8.0	0.0560	1.70	1.7	0.112
5–20	8.8	0.0392	1.35	4.5	0.182
20–40	9.1	0.0280	0.95	2.2	0.062
H 0–5	7.6	0.0616	1.59	1.0	0.137
5–20	8.3	0.0364	1.10	3.5	0.282
20–40	8.8	0.0290	0.93	1.5	0.087
I 0–5	8.6	0.0532	1.30	6.1	0.050
5–20	9.2	0.0280	0.60	12.0	0.166
20–40	9.2	0.0252	0.56	13.1	0.075
J 0–5	8.4	0.0644	1.88	2.6	0.062
5–20	9.0	0.0364	0.96	6.7	0.232
20–40	9.2	0.0260	0.80	4.0	0.062
K 0–5	8.2	0.0700	1.66	3.9	0.050
5–20	9.0	0.0308	0.76	9.3	0.149
20–40	9.2	0.0250	0.74	5.2	0.125
L 0–5	8.1	0.0728	1.62	3.0	0.062
5–20	9.0	0.0364	0.70	9.9	0.133
20–40	9.1	0.0280	0.70	6.1	0.062

Seasons of limited water supply or of high winds have retarded reclamation. There is a tendency for waste water of only fair quality to be included in the irrigation water so its quality is not greatly different from that of the drainage water at times in late season. The fall seeding has suffered at times from winter injury and the nearly pure water from the winter's precipitation has tended to drive the salts down so that surface soil was less affected in spring and seeding

TABLE 5.—*Yields of hay secured on alkali experiment plats, Vale, Ore., pounds per acre.*

Plat	Total treatment to 1933	1923	1926	1927	1928	1929	1930	1931	1932
A	Manure, 10 tons; 6 years 60 tons Sulfur, 1.5 tons	202	Green manure	3 bu. clover seed	3,300	2,160	4,580	3,720	8,180
B	Untreated	0	0	0	0	90	50	0	220
C	Manure ,8 tons; 5 years 40 tons Sulfur, 1,500 lbs	2,020	2,816	3,800	1,600	1,840	3,420	2,020	4,600
D	Manure, 8 tons; 5 years 40 tons Gypsum, 1,500 lbs.	1,700	4,107	2,000	1,540	1,540	2,740	1,400	4,140
E	Untreated	166	0	50	160	240	70	0	380
F F	Green manure, 3 tons per year Sulfur, 600 lbs.	154	1,248	4,269	1,520	1,900	2,340	2,000	2,120
G	Sulfur, 1.66 tons	350	3,110	3 bu. clover seed	3,170	Seed crop	2,780	3,200	7,940
H	Sulfur, 2.25 tons Gypsum, 1.25 tons	650	1,406	3,703	720	1,600	2,300	2,100	6,580
I	Untreated	200	0	80	80	540	400	0	400
J	Gypsum, 6.25 tons	545	Green manure	2,000	720	1,040	1,400	540	3,720
K	Gypsum, 6.8 tons	555	909	1,600	600	960	1,600	660	2,880
L	Gypsum, 10.2 tons	810	1,260	1,800	720	1,200		1,140	3,140

then is more successful. Providing the windbreak and encouraging the cover crop or the use of legume green manure as a cover has guarded against wind interference some and it seems advisable not to plow but rather to harrow and disc material into the soil so as to keep organic matter at or near the surface. As cover is established, surface evaporation is lessened, soil temperatures are lower and water is removed by the roots from below the surface rather than evaporation at the surface with consequent deposit of salt. A small field, formerly mixed sagebrush and greasewood land, that has received some 500 pounds of sulfur an acre and perhaps 8 tons of manure within the fenced experiment plat has produced excellent crops of alfalfa the past 3 years.

Recent analyses indicate fair progress has been made in the elimination of alkaline as well as saline constituents where pasturage could be established and maintained whether with or without clearing. It has been possible without chemical treatment but with copious irrigation to establish and maintain pasture of mixed clovers and grasses with fair carrying capacity. The weak carbonic acid formed by the the carbondioxide given off by the roots and organic matter has been an aid in elimination of sodium carbonate or black alkali.

DISCUSSION

In general, the results obtained with the reclamation studies reported herein have been very satisfactory and clearly indicate that black alkali soils are reclaimable. The most poorly treated plat is considerably better than the best check plat. This indicates clearly the value of the chemical treatments, and that without them reclamation would be practically impossible.

Whenever the exchange complex contains definitely more sodium than calcium the soil will be unsuited for crops. The problem is to replace the sodium on the exchange complex with calcium, which results in the restoration of a favorable soil structure. The base exchange analyses presented clearly indicate that this has been largely accomplished. From the yield data presented it can be seen that there is a good correlation between the amount of exchange calcium in the soil and the crop yield secured. This would be expected from the fact that as the amount of calcium in the soil increases the physical condition improves.

Other analytical results obtained show a marked improvement of the treated plats over the checks. A considerable number of the treated plats do not contain any carbonates in the first 5 inches, and a few of the most favorable plats do not contain any in the first 20 inches. The treated plats also show build-up in organic matter, total nitrogen, and tendency to increase in base exchange capacity and a loss in all undesirable alkali salts. The crop yields obtained and field conditions substantiate the analytical results. It is concluded (a) that black alkali soils cannot be reclaimed in any reasonable length of time by irrigation and drainage alone, although irrigation and drainage of a cleared pasture plat on the Vale experiment field has decreased the total alkali salt content about 20% as compared with the uncleared pasture land; (b) that black alkali soils can be reclaimed by the use of various chemicals as supplements to irrigation and drainage.

Crop yields and soil analyses indicate that plats A, C, F, G and H are the better plats. It will be noticed that in every case these are the plats receiving sulfur either alone or in combination with manure, green manure, or gypsum. These results indicate that sulfur is the most effective single treatment in the reclamation of black alkali soils.[4] Manure alone in moderate amounts is not effective in aiding reclamation, but sulfur and manure in combination are very effective as indicated by plats A and C, which are two of the best plats. Five hundred to 1,000 pounds of sulfur per acre are effective when used in combination with manure. If sulfur is used alone at least 1,500 pounds or more will be required in improving this soil. Gypsum and sulfur in combination give better returns than either alone as indicated by plat H which is one of the best plats. Gypsum to be effective must be applied in very heavy amounts. It is bulky and of limited solubility and even when applied in heavy amounts it lacks the solubility effect, reactivity, and the neutralizing value of the sulfur treatment.

When sulfur is applied to the soil it undergoes oxidation. The oxidation product reacts with water to form sulfuric acid. Sulfuric acid thus formed reacts with soluble sodium carbonate, exchange sodium, and calcium carbonate if present. The ultimate result is the neutralization of alkaline conditions by converting the soluble carbonate into sulfate and bicarbonate and the sodium-clay into calcium-clay. It is very important that calcium carbonate be present and fortunately most alkali soils in northwestern United States contain good supplies of this substance.

Gypsum acts promptly when applied to the soils and converts the sodium carbonate into sodium sulfate and calcium carbonate and the sodium exchange compounds into calcium compounds. Sodium in alkali soil reacts with water to form sodium hydroxide and this in turn causes the soil to become highly dispersed. The ultimate effect of any chemical treatment in order to be effective in reclamation must therefore be the conversion of the sodium carbonate into bicarbonate, sulfates, etc., which do not hydrolyze and do not cause the soil to become dispersed. When this is accomplished the soil improves in physical condition and the alkali salts can be leached out.

There has been some controversy as to what the limiting factor of plant growth is in black alkali soils. It is well known that the sodium in black alkali soils unites with water and forms sodium hydroxide. The fact that this is caustic and dissolves organic materials makes it a limiting factor. Another limiting factor would be the very poor physical condition of the soil. The high reaction may also bring toxic substances into solution. It seems that the lack

[4] Preliminary experiments indicate that volitilization of sulfur in a portable burner and absorption of the gas in irrigation water at the headgate of each plat or border-strip can be done. This should make it effective at once and permit use of cheaper lump sulfur.

of plant growth on black alkali soils is not due to any single factor but to a combination of undesirable factors.

Deep drainage and a plentiful supply of irrigation water of good quality are very essential in reclaiming black alkali soils. Supplemental chemical treatments are necessary to restore the soil structure so that the salts can be removed. All three are necessary and omitting one will limit the extent to which reclamation can be accomplished. It is well to get some resistant pasture plants growing on the soil as soon as possible as this reduces surface evaporation, removes moisture from the root zone, shades the soil, adds organic matter, and gives some returns while reclamation is in progress.

Under present economic conditions it probably costs about all it is worth to reclaim hard virgin black alkali soil and it does not seem advisable to attempt to reclaim large tracts of virgin greasewood land. Nevertheless, the reclamation investigations carried on at Vale have shown that it is possible to reclaim hard virgin black alkali soil and that it should pay to reclaim small areas on good farms as this increases the appearance and value of the farm. It also pays to reclaim "half-bad" areas of alkali land.

SUMMARY

The progress made in reclamation of hard virgin black alkali soil, and its restoration toward a normal fertile state as determined by crop yields and soil analyses, is reported for the oldest alkali experiment field in the Northwest. Sulfur, gypsum, and manure are used in various combinations and amounts as supplements to deep drainage and copious irrigation. Rye, sweet clover, and alfalfa are repeatedly seeded until a good stand of alfalfa is established.

The check plats are treated indentically as are the treated plats in every case with the exception of chemical treatments. As yet not much improvement has been noticed in the check plats which indicates that black alkali soils cannot reclaimed by irrigation and drainage alone in any reasonable length of time. The check plats contain about 4 times as much alkali salts as the treated plats. The reaction has been reduced to about pH 7.6 on some of the more favorably treated plats, while it is still on the order of pH 9.0 on the check plats.

Base exchange studies reported show that the clay-complex on the treated plats contains mainly calcium and very little sodium, while on the check plats this situation is just reversed. There is a good correlation between the crop yields secured and the amount of calcium on the exchange complex of the soil.

Sulfur has proved to be the most effective and economical single chemical treatment if used in sufficient amounts. Sulfur and gypsum used in combination are more effective than either used alone. Manure alone is rather ineffective, but 500 to 1,500 pounds of sulfur per acre used in combination with manure is very effective. One thousand pounds of sulfur per acre used with manure would perhaps give the most economical returns per unit invested. Gypsum even when used in very large amounts has been less effective than sulfur

Some of the better treated plats have given yields which compare well with those secured on the good neutral soil of the locality. The treated plats in general are giving fair yields, while as yet it has been practically impossible to get a stand on the check plats. The results obtained clearly indicate that reclamation of virgin black alkali soil is possible by the use of chemical treatments together with drainage and irrigation.

LITERATURE CITED

1. BREAZEALE, J. F., and BURGESS, P. S. Nutritional disorders in alkaline soils as caused by deficiency of carbon dioxide. Univ. Ariz. Tech. Bul. 41. 1932.
2. BURGESS, P. S., and BREAZEALE, J. F. Methods for determining replaceable bases in soils either in the presence or absence of alkali salts. Univ. Ariz. Tech. Bul. 9. 1926.
3. GEDROIZ. Nosovsk Agrl. Exp. Sta. Paper 38 : 1. 1925.
4. DESIGMOND, A. A. J. Hungarian alkali soils and methods of their reclamation. Univ. Calif. Exp. Sta. Spec. Pub. 1927.
5. HILGARD, E. W. Soils. New York : Macmillan Company. 1906. (Pages 422–484.)
6. JOHNSTON, W. W., and POWERS, W. L. A progress report of alkali land reclamation investigations in eastern Oregon. Ore. Agr. Exp. Sta. Bul. 210. 1924.
7. KELLEY, W. P., and ARANY, A. The chemical effect of gypsum, sulfur, iron sulfate, and alum on alkali soils. Hilgardia, 3 : No. 14. 1928.
8. LIPMAN, J. G. Sulfur on alkali soils. Soil Science, 2: 205. 1916.
9. POWERS, W. L. The removal of soluble salts from virgin black alkali soil. Proc. 2nd Int. Cong. Soil Sci., 5:355. 1932.
10. ————. Sulfur in relation to soil fertility. Ore. Agr. Exp. Sta. Bul. 199. 1923.
11. RATHER, J. B. An accurate loss on ignition method for determination of organic matter in soils. Univ. Ark. Bul. 140. 1917.
12. SCOFIELD, C. S. The movement of water in irrigated soils. Jour. Agr. Res., 27 : 617. 1924.

THE PERCENTAGE AND VIABILITY OF WEED SEEDS RECOVERED IN THE FECES OF FARM ANIMALS AND THEIR LONGEVITY WHEN BURIED IN MANURE[1]

GEORGE W. HARMON AND F. D. KEIM[2]

The purpose of this investigation was to determine (a) the percentage of certain weed seeds that would pass apparently uninjured through the digestive tract of farm animals, (b) the percentage of recovered seeds which were viable, and (c) the longevity of the seeds in fermenting manure.

The previous investigations which were reviewed do not include the percentage of seeds recovered from animals. Oswald (3)[3] reports an average germination of 12.8% for various seeds based upon the

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[2] Graduate student and Agronomist, respectively. Credit should be given to N. F. Petersen of the Department of Agronomy and Elva Norris, State Seed Analyst, for their helpful suggestions on the germination of the seeds, and to J. C. Russel for his constructive criticism of the manuscript.

[3] Figures in parenthesis refer to "Literature Cited," p. 767.

number of viable seeds fed to two calves when the manure was put directly on the greenhouse bench as a top dressing. All the seeds used were decomposed after 6 months burial in manure. According to Korsmo (2), seeds of many weeds were viable after being fed to either a horse, a cow, or a hog. Beach (1) found viable weed seeds in the feces from calves fed ground flax flakes. Patterson and White (4) recovered viable seeds from a cow and a horse fed grain screenings.

PROCEDURE

The following seeds were collected at Lincoln, Nebraska, for this study: Velvet weed, *Abutilon abutilon* (L.) Rusby; field bindweed, *Convolvulus arvensis* L.; white sweet clover,[4] *Melilotus alba* Desv.; smooth leaf dock, *Rumex acetocella* L.; annual smartweed, *Polygonum pennsylvanicum* L.; wild rose,[5] *Rosa arkansana* Porter; perennial peppergrass, *Lepidium Draba* L.; cocklebur, *Xanthium commune* Britton; and puncture vine, *Tribulus terrestris* L.

These seeds were germinated between blotting paper with an alternating temperature of 20°C for 16 hours and 30° C for 8 hours. To break the dormancy period of the hard seeds, the velvet weed, bindweed, peppergrass, sweet clover, smartweed, rose, and cocklebur seeds were immersed for 20 minutes in concentrated sulfuric acid (Sp. G. 1.84) after which they were washed and placed immediately on the blotters. The puncture vine and cocklebur were germinated in sand. The rose seeds were kept at 40° C for 90 days before they were placed in the germinator.

One thousand seeds of each of the first seven species were fed to two yearling calves, one yearling gelding, two yearling wethers, two hogs 4 months old, and seven cockerels 10 months old. The animals were put in a clean cement stall and fed a weed-seed-free ration for 3 days prior to the feeding of the seeds. The seeds of the seven species were mixed with the ground grain which the animals consumed in the normal manner, except the chickens which were fed the seeds in gelatin capsules.

The feces were collected every 8 hours for 4 days and the seeds recovered daily by a process of washing and decantation. The seeds that were apparently uninjured were counted and used in the germination test. After being in the germinator for 2 weeks the hard seeds were treated with concentrated sulfuric acid for 15 minutes and their total viability determined at the end of two additional weeks.

Twenty-seven lots of 100 seeds each were counted out from each species of seeds and enclosed in flat 4-inch square containers of copper strainer screen, with only the screen separating the seed and manure. Nine lots of each species were placed in piles of horse manure, cow manure, and wheat straw. Fresh manure containing a large proportion of straw was placed in piles measuring 6 feet by 10 feet by 4.5 feet high. One lot of seeds was removed each month from each pile and its germination compared to germination before burial.

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[4] Sweet clover was included among the weed seeds as a representative forage crop seed and because it sometimes contains hard seeds.

[5] Wild rose did not germinate under any of the conditions tried in this experiment. This seed, therefore, was included only in the tables showing recovery from farm animals and the effect of length of time in manure.

RESULTS

FEEDING TESTS

The percentage of seeds recovered from different classes of animals varied widely, as shown in Table 1. The average percentage of apparently uninjured seeds recovered for all species was 24.1 for the hogs, 23.1 for calves, 12.9 for the horse, 10.7 for sheep, and only 0.3 for the chickens. The chickens and to a lesser degree the sheep and the horse seemed to be able to destroy these seeds more thoroughly than the calves and the hogs.

The percentage of seeds recovered from different species was variable. The bindweed with 23.1% recovery was the least injured by all the animals, with the velvet weed almost equally durable. The smooth dock was the least durable in the animal as only 6.2% of the seeds, on an average, were recovered. When all the seeds were fed in equal amounts to all the animals, an average of 14.2% was recovered.

TABLE 1.—*The percentage of seeds recovered from farm animals fed various weed seeds.*

Kind of seeds	Percentage of seeds recovered from					
	Calves	Horse	Sheep	Hogs	Chickens	Average
Velvet weed...	45.1	16.6	12.1	38.1	1.9	22.8
Bindweed.....	38.7	10.4	15.4	51.2	0.0	23.1
Sweet clover...	16.6	19.1	8.2	31.1	0.0	15.0
Smooth dock..	7.2	10.1	9.5	4.2	0.0	6.2
Smartweed....	26.4	22.2	8.4	7.1	0.0	12.8
Wild rose......	13.3	6.8	7.6	22.7	0.0	10.1
Peppergrass...	14.2	5.2	13.6	14.0	0.0	9.4
Average.....	23.1	12.9	10.7	24.1	0.3	14.2

The Germination of the recovered seeds with and without acid treatment is shown in Table 2. When no acid treatment was used, the recovered seeds gave, on the average, a higher germination than the unfed seeds. This may be regarded as due to either one of two circumstances, *viz.*, a partial scarification in passing through the digestive tract, and a higher degree of digestion of the non-viable seeds. When acid treatment was used the average germination was lower than that of the unfed seeds, but considerably higher than where no acid was used. The smartweed seed showed a significant increase in germination when recovered from the sheep. The seeds recovered from the sheep gave the highest average germination, while those from the hogs were the lowest in percentage germination. The bindweed seeds gave the lowest germination test of all when compared with the germination of the unfed seeds.

The effect of the length of time in the alimentary tract upon the recovery and percentage germination of weed seeds is shown in Table 3. There were only one-half as many seeds recovered during the 48-

TABLE 2.—*Percentage germination of weed seeds recovered in the feces during the 4-day period following the feeding of 1,000 of each species of seeds to various farm animals.*

Kind of seeds	Percentage germination of seeds recovered from						Percentage germination before feeding
	Calves	Horse	Sheep	Hogs	Chickens	Average	
			2-week Germination Period With No Acid Treatment				
Velvet weed	7.0	15.5	11.0	16.0	61.5	12.4	5.5
Bindweed...	4.5	11.0	8.0	18.0	—*	10.4	9.3
Sweet clover	17.7	10.0	17.1	11.0	—*	14.0	7.8
Smooth dock	65.0	64.0	77.9	52.4	—*	64.8	70.5
Smartweed.	0.5	2.0	27.4	0.0	—*	7.5	0.3
Peppergrass	32.8	36.0	38.0	12.0	—*	29.7	11.8
Average..	21.3	23.1	29.9	18.2	—	23.1	15.3
			4-week Germination Period With Acid Treatment				
Velvet weed	25.0	28.0	47.0	27.0	61.5	31.8	52.5
Bindweed...	57.5	60.0	59.0	41.0	—*	54.4	84.0
Sweet clover	82.2	78.0	65.9	52.0	—*	69.5	68.0
Smooth dock	65.0	64.0	77.9	54.4	—*	65.3	85.0
Smartweed .	1.1	2.0	27.4	0.0	—*	7.6	0.5
Peppergrass	40.2	38.0	62.0	22.0	—*	40.6	34.5
Average..	45.2	45.0	56.5	32.7	—	44.9	54.1

*No seeds recovered of this species. Not included in averages.

to 80-hour period as during the 0 to 48-hour period. Also the former germinated only one-half as much as did the latter. The sweet clover seed was the only species with a higher germination for the longer period.

TABLE 3.—*The effect of length of time in the alimentary tract of calves upon the recovery and percentage germination of weed seeds.*

Length of time, hours	Velvet weed	Bind-weed	Sweet clover	Smooth dock	Smart-weed	Pepper-grass	Average
			Number of Seeds Recovered out of 1,000 Seeds Fed				
0–48......	270	220	87	32	96	90	132.5
48–80......	106	115	48	28	94	32	70.5
			Percentage Germination* of Seeds Recovered				
0–48......	11.0	7.0	5.0	26.0	1.0	33.0	13.8
48–80......	3.0	2.0	10.0	13.0	0.0	7.0	5.8

*Based upon a 2-week germination period without acid treatment.

The percentage of viable seeds recovered from 1,000 seeds of each species fed to each class of animals is shown in Table 4. This table is calculated from the percentage of seeds recovered (Table 1) and their total percentage germination (Table 2). The chickens were the most efficient destroyers of weed seeds, passing only two viable seeds out of 1,000 through their digestive tracts. The sheep, horse, hogs, and calves passed 64, 87, 88, and 96 viable seeds, respectively, per 1,000 fed.

The percentage of viable seeds recovered from the 1,000 fed to each class of animals varied according to the species. The bindweed seeds had the highest percentage recovery and germination, resulting in an average of 11.7% viable seeds recovered from all the animals. Ten per cent of viable seeds were recovered from the sweet clover. The average recovery of viable seeds per 1,000 seeds was 6.7% for all the animals.

TABLE 4.—*The percentage of viable seeds passed by the animals based upon the total number of seeds fed.*

Kind of seeds	Percentage of viable seeds passed by					
	Calves	Horse	Sheep	Hogs	Chickens	Average
Velvet weed	11.3	4.6	5.7	10.3	1.2	6.6
Bindweed	22.3	6.2	9.0	21.0	0.0	11.7
Sweet clover	13.7	14.9	5.4	16.1	0.0	10.0
Smooth dock	4.5	6.5	7.4	2.2	0.0	4.1
Smartweed	0.3	0.4	2.3	0.0	0.0	0.6
Peppergrass	5.4	19.8	8.4	3.1	0.0	7.3
Average	9.6	8.7	6.4	8.8	0.2	6.7

WEED SEEDS BURIED IN MANURE

The viability of the seeds buried in straw was not changed during the 7 months of burial since there was not enough precipitation to cause any decomposition. The temperature in the horse and cow manure reached 158° and 150° F, respectively, in 2 weeks.

The viability of the buried seeds is shown in Table 5. At the end of 1 month only the velvet weed, bindweed, peppergrass, and sweet clover were viable. The rest were partially decomposed. The bindweed and sweet clover were viable at the end of the second month, but after 3 months only one weak bindweed seedling was obtained. All the seeds at this time had started to decompose.

TABLE 5.—*The effect of length of time in manure upon the viability of various weed seeds.*

Kind of seeds	Horse manure				Cow manure				Viability before burial
	1 mo.*	2 mos.	3 mos.	4 mos.	1 mo.*	2 mos.	3 mos.	4 mos.	
Velvet weed	2.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	52.5
Bindweed	6.0	8.0	0.0	0.0	4.0	22.0	1.0	0.0	84.0
Sweet clover	14.0	4.0	0.0	0.0	22.0	4.0	0.0	0.0	68.0
Peppergrass	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.5
Smooth dock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	86.0
Smart weed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Cocklebur	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.0
Puncture vine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52.0

*Germinated without acid treatment the first month.

DISCUSSION

The limited data do not allow extensive comparison between different animals and their effect on the seeds, but the percentage recovery seemed to be correlated with the thoroughness of mastication. The individual animal, its age, condition, and the ration received no doubt has an effect upon the results obtained in an experiment of this nature. The type of manure used and the prevailing weather conditions materially affect the longevity of weed seeds when buried in manure.

SUMMARY

1. An average of 14.2% uninjured seeds was recovered from calves, horse, sheep, hogs, and chickens fed various weed seeds.
2. The germination tests without acid treatment were higher for the recovered seeds than for the unfed seeds.
3. The total germination of the recovered seeds when treated with sulfuric acid averaged 9.2% less than the total germination of the unfed seeds.
4. There were only one-half as many seeds recovered during the 48- to 80-hour period as during the 0 to 48-hour period. The former gave only one-half as high a germination as did those of the shorter period.
5. An average of 6.7% viable seeds was recovered from each 1,000 seeds fed to all the animals.
6. After being buried 1 month in cow manure and horse manure, only velvet weed, bindweed, sweet clover, and peppergrass seeds were viable. Bindweed seeds germinated 1% after 3 months in manure, while all other seeds were dead.

LITERATURE CITED

1. Beach, C. L. The viability of weed seeds in feeding stuffs. Vt. Agr. Exp. Sta. Bul. 138. 1909.
2. Korsmo, E. The viability of weed seeds after passing through the digestive tract of farm animals. Tidsshr. Norske Landbr., 18 : No. 5, 223–230. 1911.
3. Oswald, E. I. The effect of animal digestion and fermentation of manures on the vitality of seeds. Md. Agr. Exp. Sta. Bul. 128. 1908.
4. Patterson, H. J. and White, H. J. By-product feeds. Md. Agr. Exp. Sta. Bul. 168. 1908.

THE FERTILITY REQUIREMENTS OF BEDFORD SILT LOAM[1]

G. P. Walker[2]

Bedford silt loam is a rather mature limestone upland soil developed on the more gently undulating to level areas of the unglaciated region of south central Indiana, a region made famous by its output of Bedford building stone. With other types of similar fertility requirements the total area in Indiana alone is probably 500,000 acres. It is a smooth, granular, light brown silt loam to a depth of 6 to 7 inches, grading into heavier yellowish brown silt loam, underlain below depths of 20 to 30 inches by compact mottled, gray, yellow, and rust brown material. At about 40 inches a layer of tight red clay and chert appears and limestone bed rock is found at depths varying from 8 to 12 feet.

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[1] Contribution from the Department of Agronomy, Purdue University, Lafayette, Indiana. Also presented before the annual meeting of the Society in Chicago, Illinois, November 17, 1933. Received for publication March 31, 1934

[2] Associate in Soils.

Fertility studies were started on this soil type on the Bedford Experiment Field in 1917 on four series of 1/20 acre plats. This field is located on a rather level and uniform area for this region which is dotted with sink holes. It was cleared and brought under cultivation about 75 years ago. The surface soil has a pH of about 5.5 and contains approximately 2,000 pounds of nitrogen, 1,570 pounds of phosphorus, and 24,700 pounds of potassium per acre, with 13 pounds of phosphorus and 151 pounds of potassium soluble in fifth-normal nitric acid. The land was uniformly tile drained in 1916 after having been cropped to corn in 1915 and soybeans in 1916. A rotation of corn, wheat, clover, and timothy was followed until 1923 and since then one of corn, soybeans, wheat, and clover. The limed plats received 3 tons of ground limestone per acre in 1917 and another 2 tons in 1931. Clover, or a mixture of clover and alfalfa, with some Korean lespedeza in later years, has been grown regularly in the rotation, except in 1931 when soybeans were substituted after spring and fall clover seedings were lost in the 1930 drouth.

The effects on crop yields of phosphate, phosphate and potash, and nitrogen, phosphate, and potash fertilizers, alone, in addition to crop residues, and in addition to manure have been studied. The basal fertilizer formula was 2–12–4 broadcast on wheat and 0–12–4 on corn at 300 pounds per acre until 1928. Beginning in 1929, the proportion of potash was stepped up to 6%, nitrogen was added for corn, and the method of application changed to 400 pounds on wheat and 200 pounds in the row on corn. A spring dressing of 40 pounds of nitrate of soda was applied to wheat until 1927 and increased to 100 pounds in 1928. Manure, where used, has been applied for corn in an amount equal to all produce removed, except wheat grain, during the previous round of the rotation.

Fig. 1 shows the natural fertility level of the soil on this field in terms of the yields of the four crops on untreated land and on that receiving lime only. The curves show the yields for the period from 1917 to 1932 by 4-year running averages and indicate consistent lime increases on all crops.

Superphosphate alone has been very effective in increasing the yield of all crops, almost doubling the yields of wheat and hay and increasing the corn and soybean yields over 50% during the first 10-year period. The total crop increase to date accounts for about 32% of the total amount of phosphoric acid applied. Where used in addition to manure, the superphosphate has also consistently raised all crop yields and during the last half of the 16-year period its effect in addition to both manure and crop residues has been greater than where used alone. When acidity is controlled to permit regular production of the legumes in the rotation, phosphate has been the most important single factor in maintaining crop yields on this type of soil.

Potash in addition to phosphate has not been effective in increasing wheat or soybean yields and its effect on corn during the earlier years of the experiment was small. Since 1922, however, it has produced consistent corn increases and a definite trend toward

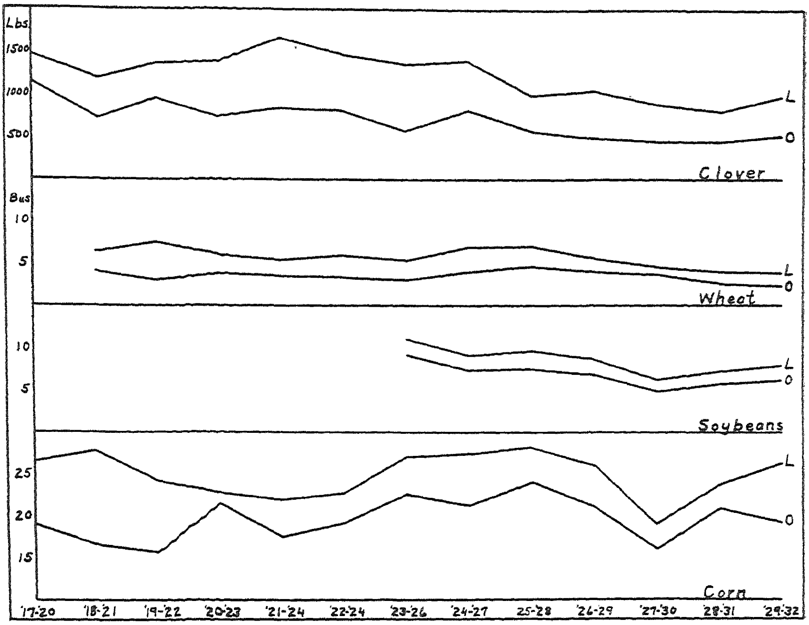

FIG. 1.—Four-year running average crop yields on untreated and limed Bedford silt loam soil.

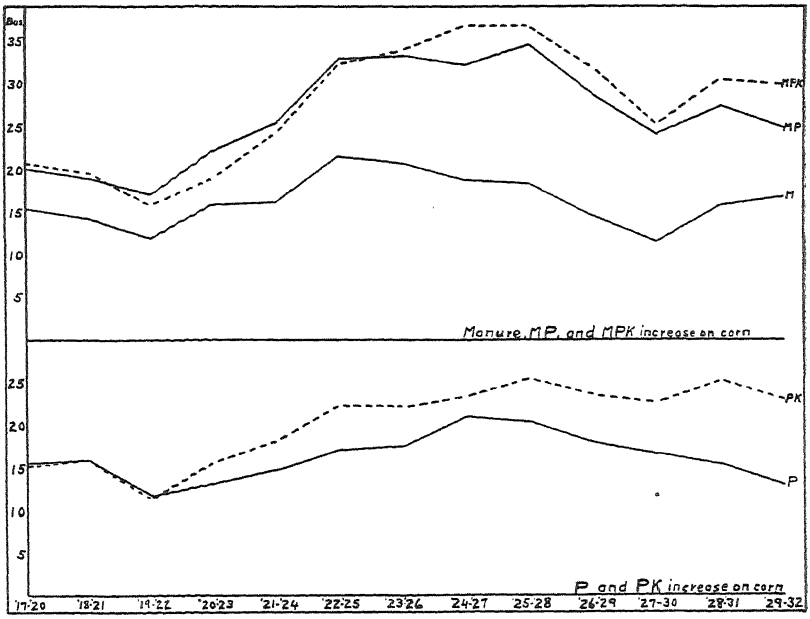

FIG. 2.—Four-year running average increases in corn yields produced by fertilizer, manure, and combinations on Bedford silt loam.

a greater response is indicated. It has produced some hay increase during recent years.

In Fig. 2 the curves in the lower section represent by 4-year running averages the corn increase in bushels for the phosphate and phosphate-potash treatments and those in the upper section the increases from manure and the combined increases of manure and each of the two fertilizers. The increase curves for the two fertilizers used without manure show a definitely widening spread since 1922 with the exception of the 4-year period ending in 1927. The results on the last two corn crops indicate that the trend shown may be more pronounced during the next few years cropping. Since 1927 phosphate alone has shown a consistent falling off in its effects, while the phosphate-potash mixture is holding its level. The upper set of curves show an increased effectiveness of phosphate in addition to manure after the 4-year period ending in 1922, with a smaller but consistent increase for added potash beginning about 1925.

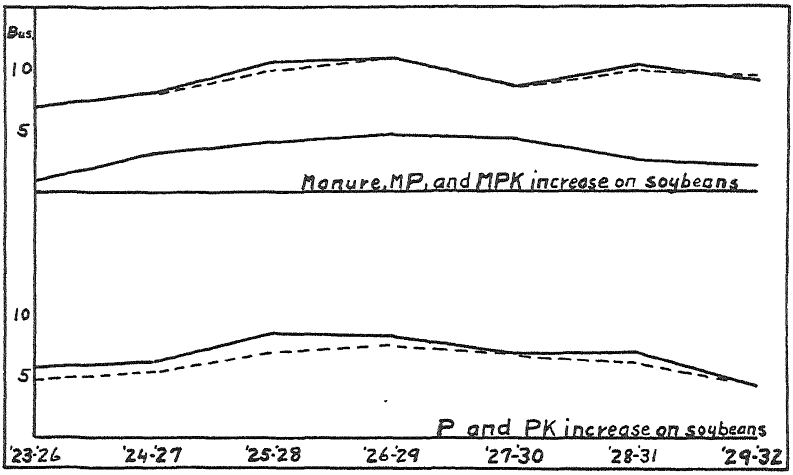

FIG. 3.—Four-year running average increases in soybean yields produced by fertilizer, manure, and combinations on Bedford silt loam. The broken lines show the combinations, including potash.

In Fig. 3 the curves for phosphate and phosphate-potash increases on soybeans are very close together throughout the period both on manured and unmanured land. The soybean crop is materially helped by the residue of the phosphate applications to corn and wheat but so far shows no response to the potash. In Fig. 4 are shown similar results on clover, although in recent years potash shows some yield advantage over phosphate alone on unmanured land. The results on this field, as on other soil types in Indiana, indicate that corn is the best potash barometer of the four crops studied.

Nitrogen, in addition to phosphate and potash, has been effective in maintaining higher yields of wheat both on manured and unmanured land, as shown in Fig. 5. Increasing the spring dressing

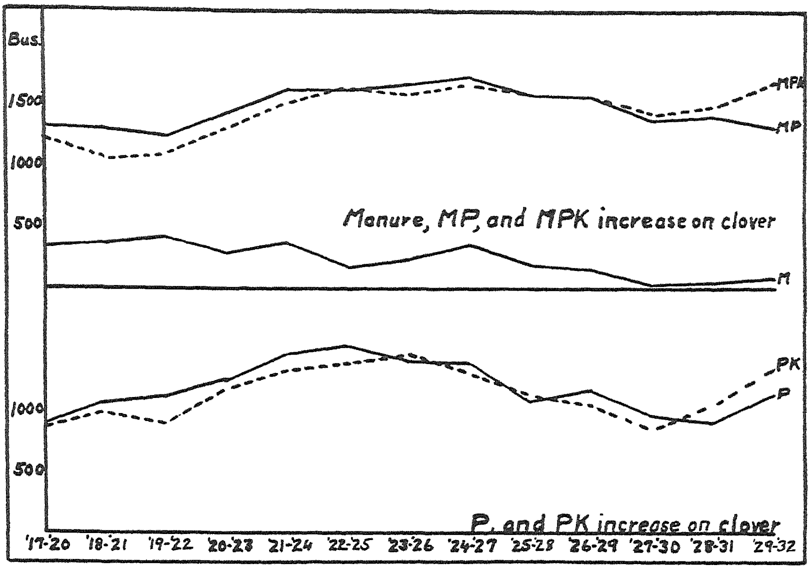

FIG. 4.—Four-year running average increases in clover hay yields produced by fertilizer, manure, and combinations on Bedford silt loam.

resulted in a sharp upturn in wheat yields in addition to that for the period of 1927–32 due to favorable seasons and nitrogen conservation during 2 dry years. These increases indicate that nitrogen has been a serious limiting factor in wheat production on this soil in previous

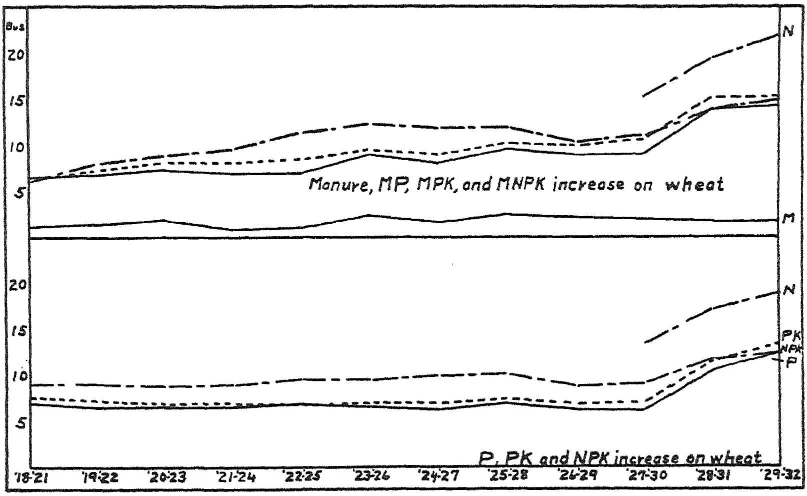

FIG. 5.—Four-year running average increases in wheat yields produced by fertilizer, manure, and combinations on Bedford silt loam, including the effect of spring top dressing with nitrate of soda.

years. Nitrogen was not applied to corn until the last 4 years when fertilizer has been applied at 200 pounds per acre in the corn row. It hardly seems reasonable that a scant 4 pounds of nitrogen per acre would consistently reduce corn yields, but such has been the results in this test. Out of 12 comparisons, adding nitrogen to the phosphate-potash mixture has produced eight decreases and three increases in corn yields with an average decrease of 2.3 bushels. Similar results have been obtained on other Indiana soil types.

In another experiment on this same field, 0.5-ton per acre applications of superphosphate at 9-year intervals have produced practically the same crop increases per unit of phosphoric acid applied as smaller applications every third year. One-ton applications of rock phosphate every 9 years have been a little more efficient than smaller amounts applied every 3 years. On unlimed areas rock phosphate is more efficient on the basis of present costs than superphosphate on this phosphate deficient soil. On limed land the opposite is true. Whether a system of fertilizing with rock phosphate without lime or using the combination of lime and superphosphate is the more practical for this type of highly responsive sour soil is debatable. Prices and accessibility of materials are the deciding factors.

It is interesting to note that, although superphosphate produces large increases in crops on this soil and potash shows an increasing effect on corn yields, none of the soil test methods for available phosphate or potash show significant differences between the fertilized and unfertilized plats. The acid-soluble methods detect rock phosphate applications.

SUMMARY

Liming has proved an important factor in raising yields of all crops to paying levels in 16 years of field plat tests on Bedford silt loam.

After liming, phosphorus was indicated as the principal plant food need of this soil for a number of years. Without manure or potash its effect is dropping rapidly in recent years.

Nitrogen in spring and fall was effective on wheat. Increasing the spring application from 6 to 15 pounds per acre has produced a 5-bushel increase per acre.

Potash in addition to phosphate showed little or no effects on wheat, soybeans, or clover. It was ineffective on corn in earlier years but has become increasingly important during the past 10 years where no manure has been used.

Manure has produced fair increases on corn and only small increases on the other crops in the rotation unless supplemented by phosphate.

A system of returning the manure produced, supplemented by 700 pounds of commercial fertilizer in the 4-year rotation on limed land has maintained yield levels of 31 bushels of corn, 9.5 bushels of soybeans, 14 bushels of wheat, and about a ton of clover hay per acre above the production levels of untreated Bedford silt loam over a 16-year period.

IMPROVEMENT OF ALFALFA SEED PRODUCTION BY INBREEDING[1]

H. M. Tysdal and Ira Clark[2]

A review of the literature suggests that the effects of inbreeding on seed production in alfalfa have not been fully established. On the whole the evidence points toward decided reduction in seed yield upon self-fertilization. Kirk (2)[3] found that as a rule the yield of seed is decreased very markedly with each generation of selfing. His data show that, as an average, the first selfed generation yielded only 62% and the S_2 30% as much as the cross-fertilized parents. Two selfed lines, however, were remarkably high in seed production, suggesting the possibility of breeding for high seed production by selection within self-fertilized lines.

Williams (4) reports that the L_1 plants (called S_1 in the present paper) considered individually were in every instance less self-fertile than their immediate parent plants. The 14 parent plants produced an average of 2,433 seeds per plant, while the average yield of the L_1 plants was only 301 seeds. In general Torssell (3) obtained similar results.

It is the purpose of this paper to report the results of selection for seed production within alfalfa lines self-fertilized up to and including the fourth generation. The effect of different environmental conditions on seed setting are also reported.

MATERIALS AND EXPERIMENTAL RESULTS

In 1932 a number of strains, including open-pollinated, S_1, S_2, and S_3 lines, were sown in the greenhouse in January and transplanted to the field in May in rows of 10 plants each with three replications systematically distributed, making a total of 30 plants per strain. The plants were set at 18-inch intervals in rows 28 inches apart with a Grimm check every seventh row. The strains consisted of open-pollinated seed from carefully selected clonally propagated individual plants; the first selfed generation from the same plants; and the second and third selfed generations obtained by self-pollination of first and second generation plants, respectively.

In 1932, three hay crops were taken from all three series. In 1933, the second crop on the first series was left for seed, the other two series being harvested for hay. The results given in Table 1 represent the seed yield per plant calculated from the yield of 10 plants for each lot. Naturally the error is high for any individual lot, the standard error calculated on the basis of 11 Grimm checks being 33% of the yield of any single row. Significant differences would therefore require a difference of 66% in yield. As a matter of fact, 5 of the 10 S_1 strains show more than a 66% reduction in yield as compared with the plants from the corresponding open-pollinated seed. It is not the purpose, however, to analyze the data in Table 1 critically from the statistical viewpoint, but rather to note the trends and general results of inbreeding. It may be concluded that in the first selfed generation there is a distinct decrease in seed production as compared to the yield of open-pollinated seed from the same plants. The average production from the 10 S_1 strains was only 40% as much as that of the plants from the open-pollinated seed. When the S_1 plants were open-pollinated, as was done in three strains, the seed production of the resulting progeny amounted to 88% of the open-pollinated.

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[1] This paper is based on cooperative investigations between the Department of Agronomy, Nebraska Agricultural Experiment Station, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Journal series paper number 150 of the Nebraska Agricultural Experiment Station. Received for publication April 6, 1934. Acknowledgment is made to T. A. Kiesselbach, Department of Agronomy, and G. L. Peltier, Department of Pathology, for helpful suggestions, and to the latter department for greenhouse facilities.

[2] Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Experimental Assistant, Department of Agronomy, Nebraska Agricultural Experiment Station, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 780.

TABLE 1.—*Seed production, in grams per plant, of self-pollinated lines of alfalfa compared to open-pollinated plants of the same strain, field results of 1933, average of 10 plants each.*

Lot	Open-pollinated	S_1	S_2 lines		S_3 lines					Open-pollinated S_1
			1	2	1	2	3	4	5	
1-01	3.8	2.2	1.8							
3-02	3.0	2.0	3.4		2.0					
4-06	3.5	0.6	1.3		4.1					4.8
5-02	3.6	1.9	2.1		2.6					
5-07	5.0	1.1	2.2	4.4	6.2	4.2	2.9	5.5	7.1	4.3
9-01	6.3	0.6	2.1		2.1					3.9
9-02	5.5	1.1								
10-01	4.8	1.1								
11-02	6.4	4.6	9.2	8.2						
19304(F.C.I. No.)	5.4	3.4								
Grimm	9.6									
Turkistan	2.4									
Av. 10 strains	4.7	1.9								
Av. 7 strains	4.5	1.9	3.9							
Av. 5 strains	4.3	1.2	2.6		4.1					
Av. 3 strains	4.9	0.8	2.5		4.6					4.3
Averages in Per cent of Open-pollinated										
Av. 10 strains	100	40								
Av. 7 strains	100	42	87							
Av. 5 strains	100	28	60		95					
Av. 3 strains	100	16	51		94					88

Three lines, *viz.*, 1-01, 5-07, and 11-02 were selected for desirable characters in the second generation, but no definite selection was made in the remaining lines. It is interesting to note that the average production of the seven S_2 lines was 87% that of the corresponding open-pollinated plants. The S_3 lines were all selected from individual plants which were high in cold and wilt resistance and of good general appearance, but had not been selected particularly for seed production. The five strains represented by S_3 lines produced 95% as much as the plants from open-pollinated seed. Some selected lines showed a tendency to greater seed production than the parent. That actual increase in seed production may be accomplished by rigid selection is demonstrated by the following results.

In January 1932, eight lots of seed were sown in plant bands in the greenhouse. Six strains had plant pedigrees and were selected from high seed-producing parents. Two commercial lots, Grimm, F.C.I. No. 15713, and Turkistan, F.C.I. 15754, were included as checks. In May, 40 seedlings of each lot were transplanted to 7-inch porous clay pots, each having one plant. An additional 10 plants of each lot were planted in the field in rows 2½ feet apart, the plants being spaced 18 inches in the row. The plants in the pots were kept in the greenhouse until they began blooming when 20 plants of each lot were transferred to a screenhouse completely inclosed with ordinary 10-mesh screen cloth. Of the 20 plants of each lot remaining in the greenhouse, the flowers of 10 were tripped by hand throughout the summer, while the other 10 were not artificially tripped. Similarly in the screenhouse, 10 were tripped and 10 not tripped. The field plants were allowed to develop normally, with unrestricted insect visitation.

The seed yields in grams per plant for the various lots under the different environmental conditions, together with the number of generations of self-pollination for each strain, are given in Table 2. Two selections, both in the third self-fertilized generation, outyielded Grimm, and all of the selected strains were superior to Turkistan. Since all but one of the selections are of Turkistan origin it is fair to compare them with the Turkistan check. Throughout all of the studies Grimm consistently outyielded Turkistan in seed production. This corresponds with field results reported by Carlson and Stewart (1) that Turkistan is the lowest seed-yielding variety tested under Utah conditions, while Grimm is one of the highest.

TABLE 2.—*Seed production in grams per plant of self-pollinated lines of alfalfa with and without tripping under different environmental conditions.*

Lot*	Generation	Greenhouse		Screenhouse		Av. yield per plant under all conditions
		Flowers tripped	Not tripped	Flowers tripped	Not tripped	
5–307–59......	S_3	2.38	0.94	0.234	0.007	0.890
5–307–104.....	S_3	1.93	0.90	0.100	0.002	0.733
Grimm........	S_0	1.44	1.24	0.066	0.024	0.693
5–307–101.....	S_3	1.88	0.78	0.058	0.002	0.680
84424–10–C_4†..	S_1	1.22	0.64	0.033	0.004	0.474
2–2 x 1–11.....	S_2	1.23	0.36	0.052	0.001	0.411
11–1 x 2–47....	S_1	1.01	0.40	0.091	0.002	0.376
Turkistan.....	S_0	0.90	0.58	0.014	0.003	0.374
Average		1.50	0.73	0.081	0.006	

*All strains of Turkistan origin except 11–1 x 2–47 which originated in Ladak.

†Selection from F. P. I. No. 84424.

Although all of the Turkistan selections yielded more than the Turkistan check, the Ladak selection, 11-1×2-47, produced the lowest yield of all selections. In all tests involving comparisons between the Grimm and Ladak varieties it has been found that Ladak is a good seed producer, averaging about the same as Grimm. Therefore, this S_1 selection from Ladak has probably decreased in seed production as compared with the parent variety.

Table 3 gives the yield in the field for 2 years of most of the lots given in Table 2. The yield was very much higher in 1933 than in 1932. This was partly due to the heavy infestation of potato leafhoppers in 1932 and partly due no doubt to the fact that the plants were much larger in 1933. With the exception of 84424-10-C_4, which had a very high yield in 1933, the relative rank of the lots reported in both tables is very similar. This indicates a relative consistency of seed yield regardless of location or environment.

TABLE 3.—*Seed production in grams per plant of advanced generations of selections compared to commercial varieties under field conditions, 10 plants of each strain having been transplanted to the field early in 1932 and allowed to produce seed 2 years.*

Lot	Generation	Seed yield per plant		
		1932	1933	Av.
84424-10-C_4*	S_1	0.09	9.9	5.00
5-307-59	S_3	0.26	7.8	4.03
Ladak	S_0	0.15	7.5	3.83
Grimm	S_0	0.15	7.3	3.73
5-307-101	S_3	0.11	5.6	2.86
11-1 x 2-47	S_1	0.17	4.7	2.44
Turkistan	S_0	0.03	3.2	1.62
2-2 x 1-11	S_2	0.06	3.0	1.53

*Selection from F. P. I. No. 84424.

In 1933 a similar study of strains was made, some of which had undergone an additional year of inbreeding. Three strains had their origin in 5-307-59, one in 5-307-104, and one in 84424-10-C_4. These can be identified by their numbers. Direct comparisons in seed production can be made between 5-307-59 and the three lines which were selected from it. The strain 5-07 is also included for comparison, this being from open-pollinated seed from the plant which was the progenitor of all 5-307- and 5-407-lines. Grimm and Turkistan were again included. The results presented in Table 4 show that all of the selections from 5-307-59 produced more than the parent itself, and from three to six times as much as the original parent 5-07. It is noteworthy that Turkistan F.C.I. No. 15754 and 5-07 are near the bottom of the list.

The strain 86664-1 was selected from one of the highest yielding plants without artificial tripping of the flowers. It is very evident that the ability to produce a large amount of seed has not been transmitted in this instance. Similarly, although the selection 15713-1s is from a very high seed-producing parent, it does not equal the general average of Grimm from which it came.

TABLE 4.—*Seed and forage production of selfed lines of alfalfa with and without tripping under two environmental conditions, the average yield of from 5 to 10 plants for each condition being reported in grams per plant.*

Lot*	Generation	Greenhouse				Screenhouse				Av. yield per plant under all conditions	
		Tripped		Not tripped		Tripped		Not tripped			
		Seed	Forage	Seed	Forage	Seed	Forage	Seed	Forage	Seed	Forage
5-407-59-11s	S_4	0.846	39	0.288	32	0.024	35	0.033	34	0.298	35
84424-10-C4-1†	S_2	0.463	32	0.378	31	0.057	28	0.001	33	0.225	31
5-407-104-11	S_4	0.768	40	0.056	38	0.052	41	0.000	35	0.219	39
11-3 x 3-13-57	S_3	0.480	42	0.335	40	0.058	38	0.000	38	0.218	40
Grimm	S_0	0.360	38	0.235	39	0.160	44	0.020	31	0.194	38
11-3 x 3-13-39	S_3	0.336	35	0.114	46	0.300	38	0.021	38	0.193	39
5-407-59-20	S_4	0.294	24	0.328	31	0.057	21	0.066	24	0.186	25
5-407-59-57	S_4	0.314	32	0.088	30	0.146	24	0.031	27	0.145	28
5-307-59	S_3	0.160	31	0.306	30	0.028	19	0.032	14	0.132	24
15713-1s	S_1	0.238	37	0.230	41	0.004	39	0.004	37	0.119	39
Turkistan	S_0	0.154	25	0.078	27	0.083	27	0.036	20	0.088	25
5-07 ck	S_0	0.125	37	0.010	39	0.032	29	0.010	26	0.044	33
86664-1‡	S_1	0.005	20	0.004	27	0.000	25	0.000	28	0.002	25
Average (omitting 86664-1)		0.378	34	0.204	35	0.083	32	0.021	30		

*All selections are of Turkistan origin except 11-3 x 3-13-57, 11-3 x 3-13-39, which are from Ladak, and 15713-1s which is of Grimm origin.

†Selection from F. P. I. No. 84424.

‡Selection from F. P. I. No. 86664.

It is clear that the mere selection of a high-yielding plant and its propagation by self-fertilization does not insure a high seed-yielding progeny. On the other hand, the results emphasize the extreme variability of this character and the necessity for including large numbers of individuals in a selection program to obtain the desired results. That increases in seed yield may be obtained by this method seems assured. The fact that few high-producing strains have been found in the S_1 but that such strains have been produced in advanced generations leads to the conclusion that selecting in advanced generations is more effective.

COMPARISON OF SEED PRODUCTION UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

As has been previously outlined, the selections under test have been allowed to produce seed under five different conditions, as follows: In the greenhouse, with and without tripping; in the screenhouse with and without tripping; and in the field.

In an effort to determine more precisely the environmental influences most effective in seed production, continuous records of temperature and humidity were obtained by means of automatic recorders in the greenhouse and in the screenhouse during the seed-setting period of 1932. In 1933 temperature records were obtained be means of maximum-minimum thermometers. No humidity records were kept in 1933. The mean maximum, mean minimum, and mean temperatures for July, August, and the first half of September for the two seasons and the maximum, minimum, and mean relative humidity for the 1932 season are given in Table 5. The de-

TABLE 5.—*Meteorological data for July, August, and the first half of September for different environmental conditions, 1932 and 1933.*

Period	Temperature, °F						Sunshine percentage of total
	Greenhouse			Screenhouse			
	Daily average maximum	Daily average minimum	Mean	Daily average maximum	Daily average minimum	Mean	
			1932				
July	96.0°	69.3°	82.7°	90.3°	69.2°	79.8°	74
Aug.	92.6°	65.5°	79.1°	85.7°	65.6°	75.7°	70
Sept. 1–15	88.9°	54.4°	71.7°	81.4°	55.8°	68.6°	63
Av. for season	92.5°	63.1°	77.6°	85.8°	63.5°	74.7°	
			1933				
July	100.4°	67.5°	84.0°	95.7°	66.4°	81.1°	80
Aug.	94.8°	65.7°	80.3°	88.2°	62.6°	75.4°	55
Sept. 1–15	93.4°	64.9°	79.2°	81.7°	61.7°	71.7°	74
Av. for season	96.2°	66.0°	81.2°	88.5°	63.6°	76.1°	
			Percentage Relative Humidity, 1932				
Av. for season	88.9	42.3	70.0	88.0	43.8	67.2	

tailed relative humidities are not given as they corresponded closely throughout the season under the two conditions. The total available sunshine in percentage for this locality is also given, the data being obtained from the records of the U. S. Dept. of Agriculture Weather Bureau Station at Lincoln, Nebraska.

As shown in Tables 2 and 4, the average yield of seed in the greenhouse was from 5 to 160 times greater than corresponding lots in the screenhouse. The differences in 1933 were not as great as in 1932, when the non-tripped screenhouse plants produced only a few seeds per plant. The humidity records in the greenhouse and screenhouse are remarkably alike and the differences would not seem to be sufficient to explain the difference in production. The plants were potted in the same size pots in the same soil, and were watered as uniformly as possible throughout the summer, and should therefore be comparable. The temperature records, however, show a considerable difference between the two conditions. In both years the greenhouse was considerably warmer, the mean maximum averaging 7.7° F higher than in the screenhouse, but differences in the minimum temperatures were slight. Greater fluctuation of temperature occurred in the greenhouse. Whether temperature was the determining factor in the differences of yield cannot be definitely concluded, but at least it was the only environmental factor measured which shows any consistent difference. There was a slight difference in insect population, the plants in the screenhouse suffering from potato leafhopper infestation late in the season, but observations earlier in the season before potato leafhoppers were a factor indicated a decided lack in seed setting in the screenhouse compared to the greenhouse, and it is clear that, while the leafhoppers may have reduced the yield, they do not account for all the differences brought out by the experiments.

DISCUSSION

The consistency with which selected advanced inbred generations maintained or even increased their seed production is contrary to the results generally obtained. At least two factors are involved that might explain the divergent results, the material used, and the breeding methods.

With regard to the material used, it may be noted that both Kirk (2) and Torssell (3) confined their selections almost entirely to the hybrid group, including Grimm and related types. Williams (4) used strains of both the common and hybrid group, but does not report which ones were used in producing his S_1 progenies. All three workers found decreased self-fertility upon inbreeding. The material which was used in the present study was largely of the Turkistan type. In the single instance where Grimm was used as the parent decreased seed production was found in the S_1. It is conceivable that different foundation material may react differently.

The second factor, the method of self-fertilization, has received serious consideration at this station. From the theoretical and methodical standpoint it is important that the selections were the result of inbreeding and not of chance crosses. Practically all of the selections here reported were the result of greenhouse inbreeding, flowers being rolled between the fingers to induce tripping; and the hands sterilized in alcohol before tripping each plant. The greenhouses were not insect proof, but very few insects capable of pollinating alfalfa gained access.

Two reasons for believing that self-fertilization usually occurs under these conditions are, first, greater uniformity in advanced generations as shown by observation and by lower coefficients of variation in green weight, number of racemes, number of pods maturing, and yield of seed; and second, during the course of these investigations several plants of *M. falcata* with pure yellow flowers self-pollinated in the greenhouse produced only yellow-flowered progeny. It seems fair to conclude, therefore, that self-fertilization has taken place in these lines.

The results with seed production of the same strains under different environmental conditions appear to point to higher temperatures, perhaps alternating temperatures, and a high percentage of total sunshine as being important factors in seed production. Moisture supplied to the plants was not a factor in these studies.

SUMMARY

Alfalfa inbreeding studies into the third and fourth selfed generations show that decreases in seed production may be expected in a general selfing program. When advanced generations were rigidly selected for this character, however, real increases in seed production were obtained in self-pollinated lines. All high seed-producing plants did not breed true for high seed production, but a sufficient number did inherit this character, particularly in the advanced generations, to give decided increases.

A study of different environments under which plants were producing seed suggested that temperature and light may have an important bearing on the amount of seed produced.

LITERATURE CITED

1. Carlson, J. W., and Stewart, G. Alfalfa seed production. Utah Agr. Exp. Sta. Tech. Bul. 226. 1931.
2. Kirk, L. E. Self fertilization in relation to forage crop improvement. Sci. Agr., 8 : 1–40. 1927.
3. Torssell, R. Självsterilitet hos luzern. Nordisk Jordbrugsforskning Beretning om N. J. F. Kongres i Helsingfors. Pages 666–669. 1929.
4. Williams, R. D. Self-fertility in lucerne. Welsh Plant Breed. Sta., Ser. H, No. 12. 1931.

THE VALUE OF SINGLE LOCK SAMPLES AS A MEASURE OF SEED PURITY IN COTTON[1]

J. H. MOORE[2]

Some cotton breeders make combings of cotton on a single seed from individual plants in order to study variability of staple length from plant to plant within any given variety or strain of cotton. A method used by some consists of picking 50 or more locks from 50 plants, combing out the fibers on the middle seed of each lock at right angles to its longitudinal axis (Fig. 1), and measuring the length. At present there does not appear to be much data on controlled tests to show the reliability of this method in measuring variation. O'Kelly and Hull[3] found that the mean combed staple length of the parent plants in cotton varieties showed correlation with the progeny length. Within the average commercial variety one can find a range of ⅛ inch or more from plant to plant in combed staple length on seeds from individual plants. Are such variations due to the genotypic constitution of the variety; or are they simple fluctuations on the plant caused by environmental conditions?

The purpose of this study is to show to what extent combed staple length as measured on a single seed of a parent is inherited or carried over to the progeny plants, and to give some measure of the value of the common method of studying length variation in cotton varieties.

MATERIALS AND METHODS

Material for study was obtained from the 1931 crop of the following American Upland strains (*Gossypium hirsutum* L.): Strain A, registered seed; Strain A, mixed seed; Strain B, certified seed; and Strain C, which appeared to be unstable. A brief history of each of the four strains is given below.

Strain A, registered seed in 1931.—Grown at this Station for 6 years. Seed were planted at Youngsville, N. C. in 1931, adjoining the mixed strain of Strain A. Blooms on individual plants were dated and tagged during the summer, and random bolls were saved from the dated material.

Strain A, mixed seed.—Grown in Union County, N. C., for 4 years, 1927–30, inclusive. No special precautions were taken to prevent mixing at gin. Seed were planted at Youngsville, N. C., in 1931, adjoining the registered seed of the same strain. Blooms were dated and tagged during the summer, and random bolls were saved from the dated material.

Strain B, grown from certified seed.—Fifty locks were picked at random from 50 plants in a grower's field in 1931 and saved for study.

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[2] Cotton Technologist. The author wishes to express his appreciation to Director R. Y. Winters for helpful suggestions in preparing the manuscript.

[3] O'KELLY, J. F. and HULL, W. W. Parent-progeny correlations in cotton. Jour. Amer. Soc. Agron., 25 : 113. 1933.

Strain C, grown from seed removed from the breeder for 1 year.— This strain showed considerable variation in combed staple length and appeared to be unstable. Fifty locks were picked at random from 50 plants in a grower's field in 1931 and saved for study.

The staple on all the seeds of each lock was then combed out at right angles to each seed, thus making the combed sample (Fig. 1).

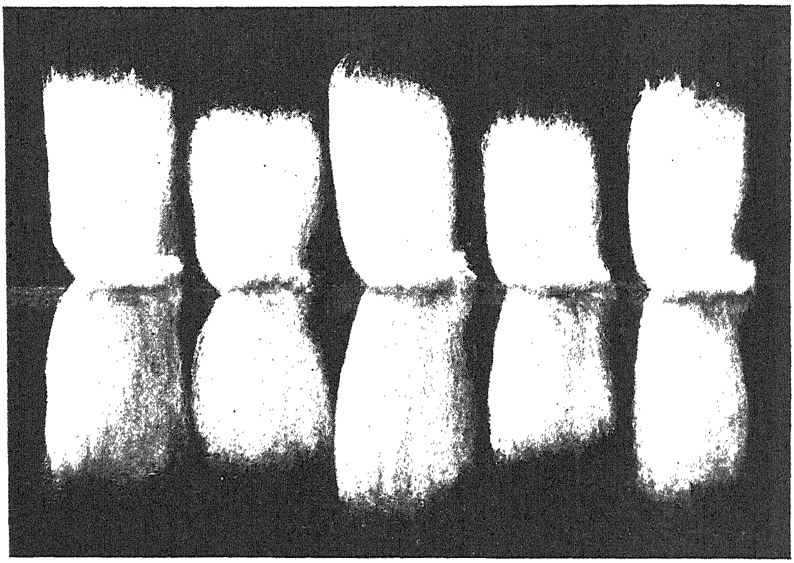

FIG. 1.—Combed staple on seeds from five random plants of one of the four cotton strains. Natural size.

The combed staple length on the seeds of each lock was measured to the nearest 1/32 inch, and the average length of combed staple in each lock was then obtained by adding the combed staple lengths on the seeds in the lock and dividing by the number used. Careful tests in the laboratory have shown that this method of measuring the staple length on a seed is accurate. There were no significant differences in the staple length on seeds within the same lock; therefore the staple length on the middle seed was similar to the average of the lock. The combed staple length of each lock was recorded, and the locks were numbered in the order of 1 to 50 in each strain of cotton. All the seed of each lock were put in small bags and saved for planting.

In the spring of 1933 the seed from the locks of the four strains were planted in hills which were numbered to correspond with each respective lock number. There were four adjacent rows, one for each strain, and 50 hills in each row. The hills were planted 2 feet apart. When about 6 inches high, the plants were thinned to three per hill. All rows and hills received similar cultural treatment and fertilization, and the soil was uniform.

When the plants were blooming freely the white blooms on each hill were tagged and dated for a period of three successive days in order to have comparable material for study.

At harvest time it was found that the boll weevils had destroyed many of the dated and tagged bolls. Some bolls were left, but not enough for comparison of the hills, therefore two undated locks were picked from two bolls of each plant. This gave a sample of six locks from six bolls of each hill for combed staple length studies. The six locks from each hill were placed in a paper bag which was numbered to correspond with that of the hill.

In the laboratory the middle seed of each lock was removed and the fibers were carefully combed out in the pattern shown in Fig. 1. The combed staple was then measured to the nearest 1/32 inch. The measurements of the staple on the middle seeds of the six locks were added together and averaged to obtain the mean combed staple length of each hill. Considerable range was noted in combed staple length of locks from the same hill. In many cases and in all the strains this range amounted to ⅛ inch or more.

EXPERIMENTAL RESULTS

Correlation coefficients were calculated for the four strains to show the relation of combed staple length in the parent and progeny plants. The correlation values are contained in Table 1.

TABLE 1.—*Correlation of combed staple length in parent and progeny plants.*

Strain	γ
A (registered seed)	.416±.074
A (mixed seed)	.491±.074
B (certified seed)	.540±.072
C (unstable seed)	.633±.060

The coefficients in Table 1 indicate that there was some degree of correlation between the combed staple length of the parents and their progeny. However, the data seem to show that a considerable percentage of the variations in staple length of parent plants were not inherent; that is, they were simple fluctuations which were probably caused largely by variation of combed staple length from boll to boll on individual plants and by environmental conditions. The distribution and correlation of staple length in the parent-progeny samples are illustrated in Fig. 2.

The standard deviations of combed staple length in the four cottons is contained in Table 2, and the correlation values of these deviations are noted for parent and progeny length.

TABLE 2.—*Correlation of standard deviations of combed staple length in parent and progeny length.*

Strain	Standard deviations of combed staple length, inches	
	Parent	Progeny
A (registered seed)	.0402±.0028	.0470±.0032
A (mixed seed)	.0606±.0042	.0554±.0038
B (certified seed)	.0615±.0044	.0529±.0038
C (unstable seed)	.0734±.0052	.0577±.0041

γ of standard deviations for length in parent-progeny samples = .967 ± .032.

The value for γ in Table 2 indicates that there was a significant correlation of the variability of combed staple length shown in the parent and progeny samples.

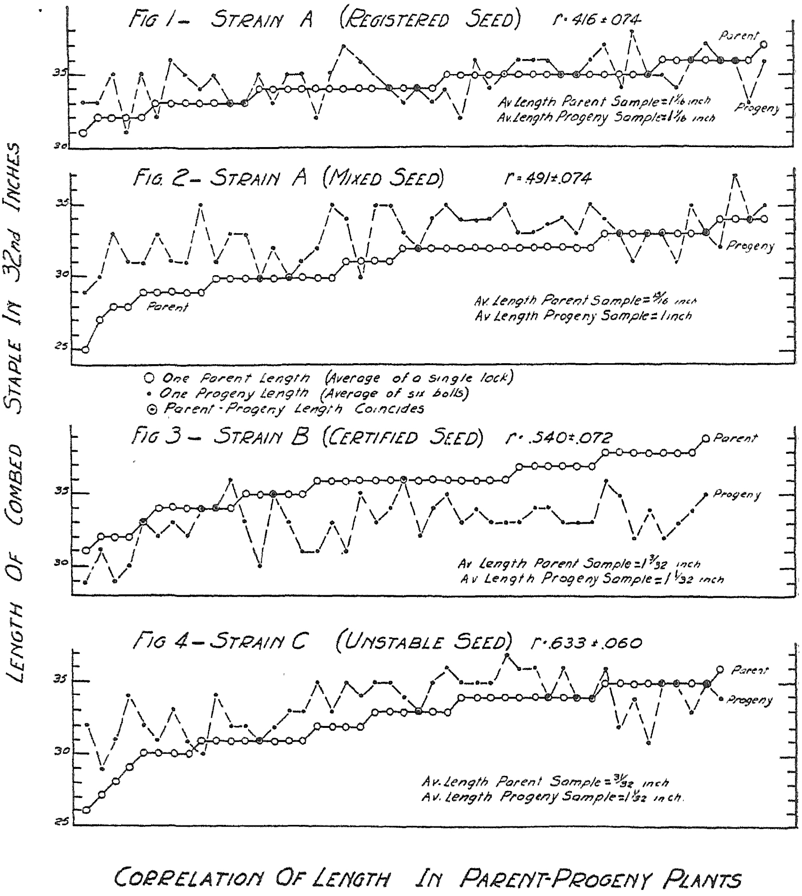

FIG. 2.—The distribution and correlation of combed staple length in the parent and progeny plants of the four strains of cotton.

CONCLUSIONS

The inheritance of combed staple length as based on the random selection of a single lock from each parent plant was studied in order to obtain data giving some idea of the accuracy of this method in measuring variability of length within a variety of cotton. Material from four American Upland strains (*Gossypium hirstum* L.), showing various degrees of variability of combed staple length, was used.

The results indicate that the correlation of combed staple length of the individual parent and progeny plants in the strains ranged from

.416 ± .074 to .633 ± .060. It appears that a considerable percentage of the variations of combed staple length were not inherent.

There was a fairly high correlation, .967 ± .032, of the standard deviations for combed staple length as measured in the parent and progeny samples.

The results for one season indicate that the method of studying variability of combed staple length by picking one lock from a plant was reasonably accurate in measuring the variability of the population of the strains studied. However, the studies indicate that many of the fluctuations noted in the parent samples were probably fortuitous; therefore the method has its limitations in the measurement of combed staple length variation as applied to the performance of individual plants within a variety of cotton.

RESPONSE OF INBRED LINES AND CROSSES IN MAIZE TO VARIATIONS OF NITROGEN AND PHOSPHORUS SUPPLIED AS NUTRIENTS[1]

Stuart N. Smith[2]

The investigation reported here deals with the results obtained from subjecting various inbred lines and their crosses to deficiencies of phosphorus and nitrogen supplied as nutrients. Differential response was found to exist and the inheritance of this response in the F_1 generation is described. The several differences observed were found to have a common cause.

ORIGIN OF THE PROBLEM

Many corn growers have held the opinion that certain varieties of corn, such as Silvermine, Silver King and Leaming, would produce better when grown on poor soils than rich-land varieties, including Reid Yellow Dent and Boone County White. Relative maturity could not account for these differences. They seemed to be connected with a differential ability to produce in the presence of a low mineral nutrient supply. This differential response may be an importance component of the adaptation complex.

The first work with inbred lines of corn on differences in functioning at different levels of fertility, was done by Hoffer (11)[3]. He found that F_1 hybrids absorbed less aluminum and iron than their inbred parents. Other work applying directly to the problems considered here is lacking.

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[1] Part of a thesis presented in partial fulfillment of the requirements for the degree of doctor of philosophy, Iowa State Agricultural College, Ames, Iowa. A complete copy is on file at the Iowa State College Library as Doctoral Thesis No. 247. Paper No. 60, Genetics Department, Iowa Agricultural Experiment Station. Received for publication April 26, 1934.

[2] Formerly Research Fellow. The author wishes to express his appreciation to Dr. E. W. Lindstrom for the use of materials and assistance which made this investigation possible and in whose laboratory the work was carried on.

[3] Reference by number is to "Literature Cited", p. 804.

MATERIALS USED

Inbred lines of dent corn were chosen for the inheritance study of nitrogen and phosphorus requirements. Open-pollinated varieties would have been altogether unsatisfactory for critical work, since they represent a mixture of genotypes. Physiological studies made with small populations of open-pollinated maize are open to serious objection. Rather large numbers are required to establish with certainty a correct average for the many genotypes involved.

Another reason for the use of inbred lines was the fact that more extreme differences could be found which gave material better adapted for a study of inheritance.

Twenty-four inbred lines and 23 F_1 crosses were studied. Four distinctive lines and their six crosses were chosen for more complete study, after many tests for elimination. These lines are designated LA, Ldg, Mc, and K 187 in the tables. LA is a tall, long-eared inbred from Lancaster Sure Crop. Ldg is very dark green, also from Lancaster. Mc is a light green early line out of Leaming. K 187 is a stiff-stalked inbred from Krug.

PLAN OF THE EXPERIMENTS

Tests were made by growing inbred lines and their crosses with limited nitrogen and phosphorus in soil, river sand, soil mixed with quartz sand, quartz sand, and particularly in water cultures. These tests were made in the greenhouse over a 2-year period. Dry weight of the entire plant at about 6 weeks of age was used as the best index of response to the nutrient supply. One test was made in the field and ear weights recorded.

Differences due to stored food in the endosperm were minimized by selection for uniform seed size within a line. Reciprocal crosses were used in the inheritance studies on the four principal lines excepting Mc x Ldg, where the reciprocal was not obtained due to a maturity difference between the parents.

A mercury dust disinfectant was used to control loss of plants from seedling diseases.

In the water culture tests, seedlings of the inbred lines and their hybrids were germinated over a weak nutrient solution and transplanted to the culture jars when they were about 3 inches high. Such seedlings, when transplanted to tap water failed to show further increase in growth. This would indicate that growth resulting from stored food in the endosperm represented a very small fraction of the growth obtained in the cultures.

Quart Mason jars were used, fitted with standard two-hole corks impregnated with Merko on the under side to control molds. The two plants from each jar were handled as a unit in obtaining the dry weights.

The plants in soil, sand, and mixtures of both were grown in gallon size stone jars and thinned to a uniform stand after germination. These media were useful in checking the results obtained from water cultures but were not considered to be as satisfactory for a critical study of nutrient needs in plants. This is particularly true of phosphorus absorption because of its rapid fixation in soils as described by Truog (14), Balonesco (2), and Ford (6).

The nutrient solution used in the water culture experiments follows:

	Grams per liter
KCl	0.288
$MgSO_4$	0.432
$Fe_2(C_4H_4O_6)_3$	0.100
KH_2PO_4 (substitute KCl)	0.066
$(NH_4)_2SO_4$ (substitute K_2SO_4)	0.072
$Ca(NO_3)_2$ (substitute $CaSO_4$)	0.200

The high iron content was required to prevent chlorosis in the plants, since iron precipitated out rather rapidly in the basic tap water (pH 7.2) used in making up the solutions.

It will be noted that the phosphorus supply is made low in order to study differential plant growth at or near the critical level. In this range some inbred lines die on the lower levels of phosphate concentration, while others show only a decreased growth, and it is here that critical inheritance studies of mineral nutrient needs should be made. With some essential elements, such as iron and calcium, this range is very narrow, but with phosphorus it is considerably broader.

The physiology of death from phosphorus starvation has been outlined by Eckerson (5) for the tomato. It appears to be quite similar with corn. Starved plants develop a grayish appearance and death begins at the tip and margins of the older leaves, sometimes at the base, proceeding inward to the midrib. In the early stages growth in stem diameter is retarded more than length.

The water culture tests were made with a full nutrient solution as the basis of comparison within a line. Growth on this solution usually equalled normal growth for the same lines when grown in soil. Nitrogen studies were made by limitation of nitrogen supplied to 0.05 and 0.01 of the amount supplied in the full nutrient solution with substitutions as indicated above. Differential response to nitrogen deficiencies was much less striking than with phosphorus. Phosphorus supply was reduced to 0.5, 0.2, 0.05 and 0.01, with the proper substitutions. The pH of the several solutions remained practically uniform throughout the tests.

Total dry weight was determined when the plants were about 6 weeks of age, since it was considered that this period covered the most important part of the plant's life with respect to phosphorus absorption. Brenchley (3) and Tueva (15) reported that barley absorbed enough phosphorus from water cultures in the first 5 to 6 weeks to support normal growth thereafter. When the element was limited during the first 4 weeks and then supplied, no heads formed. Gericke (7, 8) obtained similar results with mineral elements required by the wheat plant, with the exception of calcium and iron. It was found in the present investigation that maximum differences between lines on low phosphorus appeared by the end of the sixth week.

RESULTS

Results are expressed in the tables in terms of percentages based on dry weight. Growth for any given inbred or hybrid where nutrients were at optimum was taken as 100%. In testing the effect of a limited phosphorus supply on the growth of the several inbred lines of maize and their crosses, the aim was to determine the potential growth for any given genotype as compared with the same genotype with adequate phosphorus supply. The efficiency of the several genotypes might then be compared better than in terms of net dry weight.

Many preliminary tests were made to find inbred lines which displayed distinct differences in their growth with a low phosphorus supply. These tests involved ability to produce ears as well as satisfactory plant growth when supply of the element was below optimum.

Final selection of four inbred lines was made on the basis of a test involving response to phosphate fertilizer on a soil which had been heavily cropped and was deficient in the element. The four lines, LA, Ldg, Mc, and K 187, have been described above.

These four lines with their six crosses were grown in 10 replications in the greenhouse on full nutrient and 1/20 phosphorus solutions and the results appear in Table 1. Lines K 187 and Mc showed relatively good growth on the low phosphorus treatment, while LA and Ldg were much poorer. This was in agreement with preliminary experiments. The hybrid between the two efficient lines, Mc and K 187, showed no evidence of complementary action of efficiency factors. This was also the case with the hybrid between the two inefficient sorts, LA and Ldg. No evidence was found of physiologic stimulation in this cross which would enable it to show materially better growth on low phosphorus than either parent.

On the other hand, Mc which yielded on low phosphorus 59.8% of its yield on full nutrient and K 187 (67.4%) crossed with LA (29.8%) gave hybrids showing 57.5% and 58%8, respectively, on low phosphorus. Similarly, the efficient lines when crossed with Ldg (28.3%) resulted in yields of 69.5% with Mc and 80.1% with K 187. Thus, where one parent of the hybrid was phosphate efficient, the cross was at least as good as the better parent in this respect. Ashby's work (1) dealing with inbred lines of maize with unlike growth rates showed that the growth rate of the F_1 hybrid resembled that of the faster growing parent.

In a later test the four lines were grown on a series of phosphorus limitations, again with 10 replications. Photographs of representative plant growth appear as Figs. 1 and 2. From the data in Table 2 it will be seen that the line Mc showed consistently less damage from the low phosphorus treatments. It was followed by K 187, but both LA and Ldg were distinctly inferior, with death on the lower phosphorus levels. This strengthened the belief that the genotypes under consideration differed sharply in ability to absorb or use phosphorus at low levels.

Table 3 shows the results of a repetition of the comparison reported in Table 2 with the addition of the six crosses of the four inbreds

TABLE 1.—*Dry weight in grams of four inbreds and six crosses on full nutrient, 1/20 phosphorus, and 1/20 nitrogen solutions.**

Inbred lines and crosses	Full nutrient		1/20 phosphorus		1/20 nitrogen	
	Total	Roots	Total	Roots	Total	Roots
K 187	4.06±0.36†	0.90±0.09	2.74±0.12	0.90±0.04	2.58±0.17	0.91±0.05
Mc x K 187	6.10±0.30	1.81±0.09	4.26±0.12	1.50±0.04	3.76±0.07	1.33±0.02
Mc	4.45±0.25	0.84±0.11	2.26±0.14	0.55±0.05	2.05±0.05	0.37±0.04
La x Mc	5.73±0.36	1.35±0.12	3.30±0.11	1.06±0.04	5.16±0.23	1.55±0.09
La	3.46±0.33	0.63±0.08	1.03±—	0.20±—	1.28±0.10	0.30±0.03
La x Ldg	4.53±0.19	1.24±0.07	1.68±0.06	0.50±0.01	1.62±0.07	0.47±0.04
Ldg	4.30±0.21	1.12±0.07	1.22±0.08	0.31±0.02	2.03±0.10	0.61±0.05
Ldg x K187	4.33±0.31	1.32±0.09	3.53±0.10	1.20±0.04	3.51±0.23	1.05±0.09
La x K187	4.10±0.35	1.20±0.11	2.41±0.10	0.84±0.04	2.80±0.16	1.01±0.07
Mc x Ldg	3.78±0.35	1.12±0.10	2.62±0.08	0.92±0.03	2.74±0.12	1.03±0.05

*Ten replications, two plants per jar. Nov. 8 to Dec. 29, 1932.
†Standard error.

TABLE 2.—*Dry weight in grams of four inbred lines grown in water cultures.**

Inbred lines	Full nutrient		½ phosphorus		1/5 phosphorus		1/20 phosphorus	
	Total	Roots	Total	Roots	Total	Roots	Total	Roots
Ldg.	4.84±0.29† 100%	1.33±0.11	3.01±0.17 62.2%	0.90±0.07	1.72±0.12 33.5%	0.47±0.04	0.88±0.06 18.2%	0.22±0.20
La.	3.55±0.27 100%	0.80±0.08	3.18±0.19 89.6%	0.77±0.06	1.55±0.10 43.6%	0.32±0.02	1.07±0.11 30.1%	———
Mc.	3.35±0.18 100%	0.65±0.04	3.26±0.14 97.3%	0.67±0.09	3.11±0.11 92.8%	0.71±0.05	2.59±0.17 77.3%	0.66±0.04
K 187	5.24±0.53 100%	1.37±0.17	4.37±0.50 83.4%	1.13±0.15	3.20±0.17 61.0%	0.91±0.04	2.59±0.08 49.2%	0.77±0.04

	1/100 phosphorus		1/20 nitrogen		1/100 nitrogen	
	Total	Roots	Total	Roots	Total	Roots
Ldg.	0.68±0.03 14.0%	0.20±0.01	1.67±0.08 34.5%	0.39±0.04	1.76±0.11 36.3%	0.41±0.05
La.	0.64±0.05 18.0%	0.13±0.02	3.75±0.24 105.6%	0.81±0.06	2.25±0.16 63.4%	0.50±0.05
Mc.	1.99±0.10 59.4%	0.47±0.02	1.96±0.19 58.5%	0.39±0.05	1.43±0.14 42.7%	0.23±0.02
K 187	2.09±0.12 39.8%	0.71±0.04	2.70±0.21 51.5%	0.65±0.06	2.13±0.17 40.6%	0.56±0.07

*Ten replications, two plants per jar. Dec. 30, 1932, to Feb. 17, 1933.

†Standard error,

studied. Dominance of phosphate efficiency is clearly apparent, though in general not as extreme as in the results reported in Table 1. With the exception of LA x Mc and Mc x Ldg, the hybrids exceed the better parent somewhat on the one-half phosphorus solutions, indicating that some hybrids might be expected to produce better than the better inbred parent in the first stages of phosphorus deficiency but drop below it as the deficiency increases.

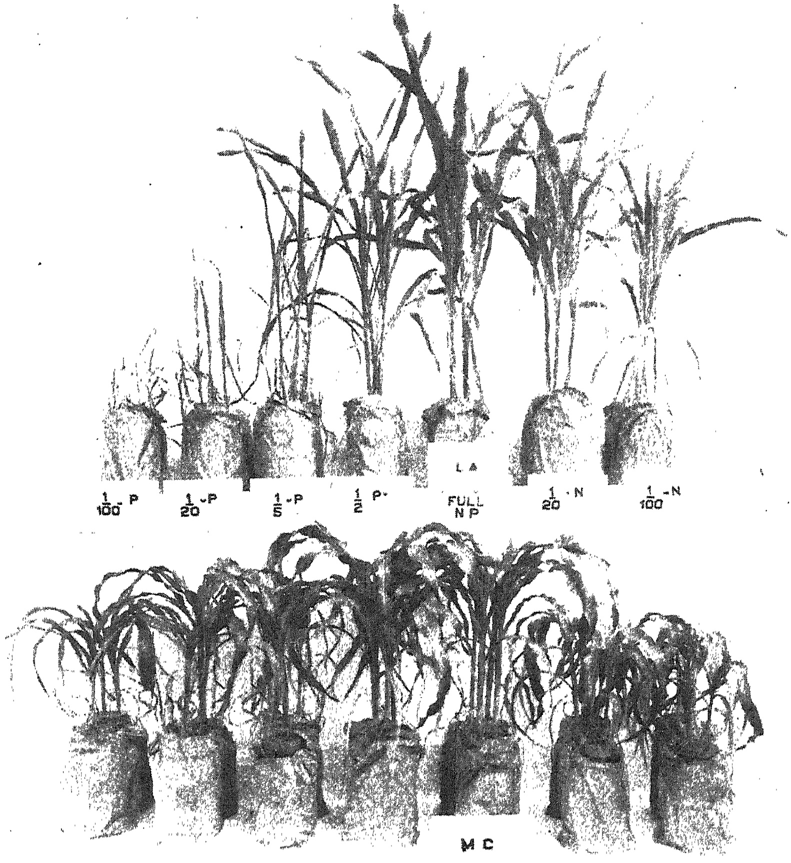

FIG. 1.—Representative growth of inbred lines LA and Mc at 6 weeks of age. Plants grown in water cultures with a series of phosphorus and nitrogen limitations.

There again appeared to be no advantage in percentage growth on low phosphorus by combining the two efficient lines Mc and K 187 and no clear evidence of physiologic stimulation as a cause of hybrid vigor in the cross of the two inefficient types LA x Ldg.

Table 4 reports a repetition of the experiment described above, with very similar results. The tendency of the hybrids to exceed the

TABLE 3.—*Dry weight in grams of four inbreds and their six crosses grown in water cultures.**

Inbred lines and crosses	Full nutrient		1/2 phosphorus		1/5 phosphorus		1/20 phosphorus	
	Total	Roots	Total	Roots	Total	Roots	Total	Roots
Mc.	4.02±0.07† 100%	1.40±0.14	3.86±0.29 96.0%	1.38±0.11	2.64±0.09 65.6%	0.96±0.07	1.90±0.14 47.2%	0.94±0.07
La x Mc.	9.16±0.12 100%	3.14±0.08	7.56±0.28 82.5%	2.56±0.11	5.26±0.40 57.4%	2.04±0.14	3.26±0.22 35.6%	1.02±0.02
La.	6.12±0.38 100%	2.08±0.18	2.82±0.17 47.0%	0.94±0.07	1.60±0.15 26.6%	0.42±0.04	0.74±0.11 12.4%	0.24±0.03
La x Ldg.	6.42±0.33 100%	2.28±0.23	4.66±0.30 72.5%	1.96±0.13	2.64±0.20 41.4%	0.98±0.07	1.50±0.07 25.3%	0.54±0.03
Ldg.	5.12±0.18 100%	1.78±0.08	3.12±0.23 60.9%	1.18±0.07	2.24±0.16 43.7%	0.86±0.10	1.22±0.05 23.8%	0.38±0.02
Ldg x K 187.	7.88±0.27 100%	2.74±0.24	7.04±0.35 89.3%	2.16±0.11	5.10±0.44 64.7%	1.66±0.05	2.44±0.22 30.9%	0.94±0.07
K 187.	4.70±0.41 100%	2.62±0.09	3.48±0.24 74.0%	1.48±0.15	2.84±0.24 60.4%	1.20±0.11	1.78±0.08 37.9%	0.84±0.05
La x K 187.	9.24±0.41 100%	3.16±0.06	7.56±0.54 81.8%	2.56±0.06	5.34±0.24 56.6%	1.86±0.14	2.90±0.17 31.3%	1.16±0.08
Mc x K 187.	8.84±0.39 100%	2.44±0.17	8.80±0.53 99.5%	2.54±0.41	6.76±0.45 76.4%	1.90±0.16	2.70±0.34 30.5%	0.80±0.11
Mc x Ldg.	7.00±0.18 100%	2.76±0.08	5.82±0.20 83.1%	2.18±0.05	4.26±0.19 60.9%	1.82±0.12	2.38±0.22 34.0%	0.80±0.05

	1/100 phosphorus		1/20 nitrogen		1/100 nitrogen	
	Total	Roots	Total	Roots	Total	Roots
Mc	1.42±0.09 33.9%	0.60±0.03	2.32±0.12 57.7%	0.82±0.02	2.06±0.17 51.2%	0.74±0.08
La x Mc	2.32±0.10 25.3%	0.78±0.06	4.46±0.24 42.7%	1.90±0.11	3.78±0.07 41.2%	1.54±0.11
La	0.68±0.04 11.3%	0.18±0.02	2.84±0.08 47.3%	1.02±0.04	2.80±0.18 46.6%	1.12±0.06
La x Ldg	1.20±0.08 18.7%	0.28±0.04	2.82±0.22 43.9%	1.22±0.12	2.38±0.19 37.1%	1.06±0.06
Ldg	1.00±0.08 19.3%	0.28±0.02	2.32±0.11 44.5%	0.78±0.07	1.92±0.13 37.5%	0.68±0.06
Ldg x K 187	1.84±0.11 23.4%	0.76±0.05	4.18±0.11 53.0%	1.68±0.11	3.52±0.09 44.7%	1.38±0.04
K 187	1.64±0.05 34.9%	0.76±0.04	2.92±0.11 62.1%	1.32±0.07	2.62±0.19 55.7%	1.00±0.08
La x K 187	2.54±0.06 27.5%	1.00±0.06	3.88±0.26 41.9%	1.66±0.09	3.58±0.16 38.7%	1.46±0.12
Mc x K 187	1.98±0.18 22.4%	0.74±0.03	4.86±0.06 54.9%	1.74±0.03	4.06±0.08 45.9%	1.28±0.12
Mc x Ldg	2.12±0.20 30.3%	0.80±0.03	3.50±0.08 50.0%	1.56±0.05	3.20±0.12 45.7%	1.38±0.07

*Five replications, two plants per jar, Feb. 17 to Apr. 1, 1933.

†Standard error.

TABLE 4.—*Dry weight in grams of four inbreds and six crosses grown in water cultures.**

	Mc	LA x Mc	LA	LA x Ldg	Ldg	Ldg x K 187	K 187	LA x K 187	Mc x K 187	Mc x Ldg
					Full Nutrient					
Roots.........	1.7 1.1 1.7 1.7 1.6	2.3 1.5 2.1 2.2 2.1	1.8 1.6 1.6 1.7	2.1 1.8 2.0 2.3	1.7 1.7 1.8 1.8	2.7 2.8	2.1 2.3	1.9 1.4	2.8 2.8	2.1 2.3
Total.........	4.6 3.0 4.5 4,3 4.0	5.0 3.9 4.9 5.0 5.0	4.6 4.2 4.2 4.6	4.9 5.3 4.8 5.1	3.7 4.0 4.0 3.7 3.6	6.0 6.0	4.5 4.5	5.0 4.2	5.8 5.8	4.9 5.0
Average total	4.08	4.95	4.90	5.02	3.80	6.00	4.50	4.60	5.80	4.95
Per cent.....	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
					½ Phosphorus					
Roots.........	1.3 1.1 1.4 1.2 1.4	1.6 1.4 1.5 1.5 1.6	1.2 0.9 0.9 0.9	1.1 1.5 1.1 1.4	0.9 0.7 0.8 1.0 0.9	1.5 2.2	1.5 1.3	1.7 1.5	2.4 2.6	1.7 1.3
Total.........	2.9 2.5 3.1 2.5 2.8	3.6 3.1 3.2 3.1 3.4	2.5 2.0 1.9 2.0	2.9 3.4 3.0 3.0	1.8 1.8 1.7 1.8 1.9	3.8 4.6	3.2 3.0	3.8 3.3	5.1 5.5	4.2 3.7
Average total	2.76	3.28	2.10	3.07	1.80	4.20	3.10	3.55	5.30	3.95
Per cent.....	67.6	66.2	42.8	61.1	47.3	70.0	68.9	77.1	91.3	79.7

					1/5 Phosphorus					
Roots.........	0.8 1.1 0.7 0.7 0.9	1.0 1.2 1.0 1.0 1.1	0.7 0.7 0.8 0.8	1.1 0.8 1.1 1.1	0.8 0.7 0.5 0.7 0.7	1.8 1.6	1.6 1.2	1.1 1.0	1.9 2.0	1.3 1.2
Total.........	2.5 2.4 2.3 2.1 2.9	2.3 3.1 2.8 2.4 2.7	2.1 2.0 2.0 2.1	2.4 2.0 2.6 2.6	1.7 1.9 1.8 1.2 1.6	3.8 3.5	3.3 3.1	3.1 3.0	4.3 4.3	3.1 3.0
Average total	2.44	2.66	2.05	2.40	1.64	3.65	3.20	3.05	4.30	3.05
Per cent.....	59.8	53.7	41.6	47.8	43.2	60.8	71.1	66.1	74.1	61.6
					1/20 Phosphorus					
Roots.........	1.1 1.0 1.2 1.1 1.1	1.2 0.9 1.0 0.9 1.9	0.5 0.7 0.7 0.5	0.7 0.6 0.7 0.8	0.6 0.5 0.6 0.5 0.5	1.2 1.2	1.1 0.9	0.6 0.7	1.4 1.6	0.8 0.8
Total.......	2.3 1.9 2.2 2.1 2.5	3.4 2.4 2.5 2.4 2.3	1.1 1.7 1.5 1.4	1.7 1.2 1.9 1.6	1.4 1.1 1.4 1.2 1.1	2.9 2.7	2.4 2.0	2.0 2.0	3.1 3.3	1.8 2.0
Average total	2.20	2.60	1.42	1.60	1.24	2.80	2.20	2.00	3.20	1.90
Per cent.....	53.9	52.5	28.9	31.8	32.6	46.7	48.8	43.5	55.2	38.3
					1/100 Phosphorus					
Roots.........	0.8 0.7 0.5 0.8 0.8	0.7 0.6 0.7 0.7 0.8	0.4 0.4 0.5 0.5	0.8 0.5 0.5 0.7	0.4 0.5 0.3 0.3 0.4	0.9 0.9	0.9 0.9	0.7 0.7	1.0 1.0	0.7 0.6
Total.........	1.9 1.8 1.4 2.0 1.8	1.9 1.6 2.0 1.7 1.7	0.9 0.9 1.1 1.1	1.4 1.2 1.2 1.3	1.0 1.1 0.9 0.9 1.0	2.0 1.9	1.8 1.7	1.6 1.7	2.3 2.4	1.5 1.5
Average total	1.78	1.78	1.00	1.27	0.98	2.00	1.75	1.65	2.35	1.50
Per cent.....	43.8	35.9	20.4	25.3	25.7	33.3	38.8	35.9	40.5	30.3

TABLE 4.—*Concluded.*

	Mc	LA x Mc	LA	LA x Ldg	Ldg	Ldg x K 187	K 187	LA x K 187	Mc x K 187	Mc x Ldg
					1/20 Nitrogen					
Roots.........	1.0	1.3	1.3	0.9	1.1	1.7	1.1	1.1	1.7	1.1
	0.9	1.2	1.1	1.1	1.4	1.7	1.2	1.4	1.7	1.4
	1.0	1.3	0.9	1.1	1.5					
	1.0	1.1	1.0	1.2	1.1					
	1.1	1.2			1.1					
Total.........	2.4	3.1	3.1	2.4	2.9	3.5	3.0	3.5	4.0	2.7
	2.2	2.7	2.7	2.9	2.7	3.5	2.5	3.0	3.6	3.2
	2.3	2.8	2.6	2.7	2.8					
	2.3	2.6	2.7	2.7	2.5					
	3.0	2.9			2.7					
Average total	2.44	2.82	2.77	2.67	2.72	3.50	2.75	3.25	3.80	2.95
Per cent.....	59.8	56.9	56.4	53.2	71.5	58.3	61.1	70.6	65.5	59.6
					1/100 Nitrogen					
Roots.........	1.4	1.4	1.5	1.3	1.2	1.4	1.7	1.3	1.5	1.0
	1.0	1.4	1.5	1.2	1.1	1.4	1.3	1.4	1.5	1.1
	1.5	1.4	1.6	1.1	1.1					
	1.3	1.4	1.6	1.1	1.2					
	1.1	1.2			0.8					
Total.........	3.4	2.9	2.8	2.7	2.7	2.7	3.3	2.7	3.0	2.3
	2.3	2.7	3.0	2.5	2.7	3.0	2.5	3.2	2.9	2.3
	2.8	2.9	2.8	2.2	2.5					
	2.8	3.0	3.0	2.1	2.6					
	2.6	2.5			2.1					
Average total	2.78	2.80	2.90	2.37	2.52	2.85	2.90	2.95	2.95	2.30
Per cent.......	68.1	56.5	59.1	47.2	66.3	47.5	64.4	63.9	50.9	46.4

better parent on the one-half phosphorus treatment was again apparent, with rather complete dominance of the more efficient parent on the other low phosphorus levels.

Since the technic of the experiments reported in Tables 3 and 4 was the same, it is possible to summarize the results (Fig. 3). The conclusion is drawn that ability to maintain relatively good growth on a low level of phosphorus is inherited and that it is dominant over lack of such ability. Complementary action of factors might explain the situation equally well were it not for the fact that there are four crosses involving one efficient and one inefficient line, behaving very much alike. It would be unusual to find about the same degree of complementary action in four different crosses.

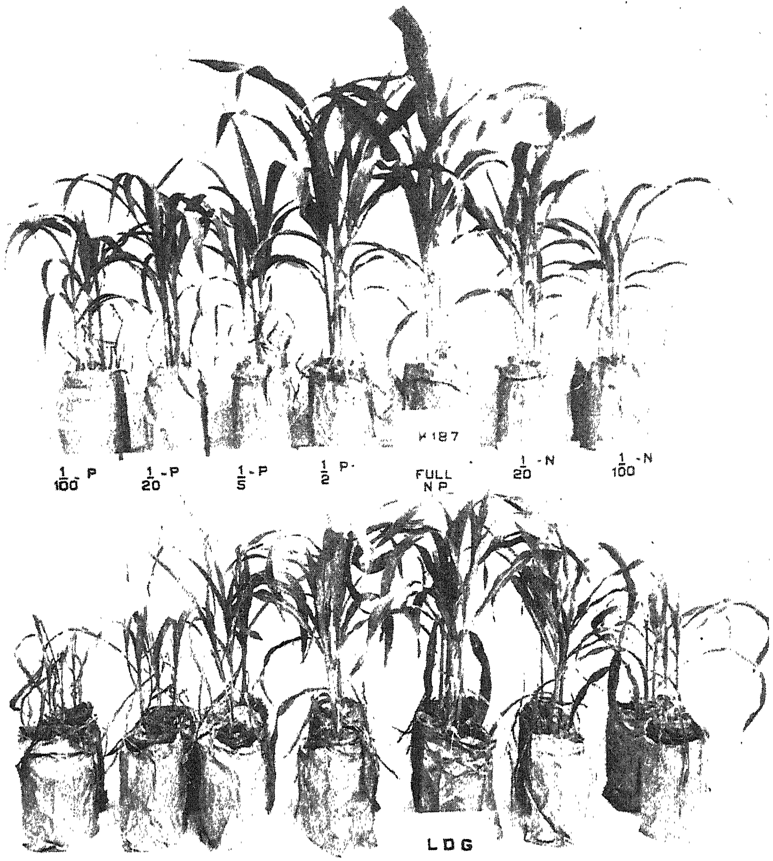

FIG. 2.—Representative growth of inbred lines K/87 and Ldg at 6 weeks of age. Plants grown in water cultures with a series of phosphorus and nitrogen limitations.

The percentage growth of the four lines and their crosses on a limited nitrogen supply appears in Fig. 3. Since the four inbreds differed little in the use of nitrogen at low levels, no conclusions could be drawn from their hybrids.

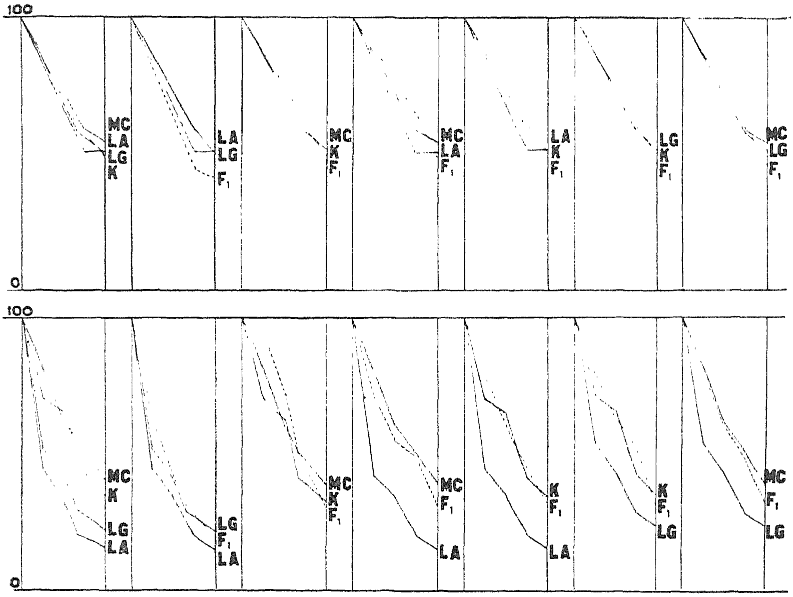

FIG. 3.—*Above*, dry weight of four inbred lines and their six hybrids on full nutrient, 0.05 nitrogen, and 0.01 nitrogen solutions. *Below*, same inbred lines and hybrids grown in full nutrient, 0.5, 0.2, 0.05, and 0.01 phosphorus solutions Data from Tables 3 and 4 expressed in %.

The analysis of variance is shown in Table 5. It will be seen that differences between lines and between treatments were significant. Variation between experiments was of less importance. Although general plant growth was better in the spring-grown experiment 4 than in the wintergrown experiment 2, relative response of the lines remained the same.

TABLE 5.—*Analysis of variance of the data in Tables 2, 3, and 4.*

Variation	Sum of squares	Degrees of freedom	Mean squares	½ $\log_e$	z
Between lines	5,848.25	3	1,949.41	3.7876	1.4906
Between experiments	897.90	2	448.95	3.0534	0.7564
Between treatments	12,558.83	5	2,511.76	3.9143	1.6173
Inter. line and experiment	2,536.11	6	422.68	3.0221	0.7251
Inter. line and treatment	3,793.21	15	229.28	2.7174	0.4204
Inter. experiment and treatment	1,928.57	10	192.85	2.6309	0.3339
Inter. line and experiment and treatment	2,967.15	30	98.90	—2.2970	
Total	30,530.02	71			

REASONS FOR NUTRIENT EFFICIENCY

Ability to grow relatively well with a low phosphorus supply might be accounted for in several ways. The phosphorus metabolism of the plant might permit re-utilization of the element in periods of shortage. DeTurk, Holbert, and Howk (4) did not find this to be true with corn.

An inherited difference in percentage composition might result from a lower requirement of phosphorus per unit of dry matter. Phosphorus analyses of the lines LA, Ldg, Mc, and K 187 failed to show any correlation between composition and efficiency.

Differential excretion of CO_2 by the roots of maize lacks proof, as does the theory of energy exchanges involved in absorption of nutrients, suggested by Hoagland (10).

In this investigation, inherited differences in root type appear to account for differences in growth. Heavy crops of the four inbred lines were grown in jars and the soil tested for available phosphate after the crop was matured, using the Harper method (9). Less soluble phosphate remained after growth of the efficient lines Mc and K 187 than after that of LA and particularly Ldg (Table 6). Efficiency of phosphate absorption was found to be correlated with high phosphorus content in the plant when subjected to the test described by Thornton (13). Results of this test appear in Table 7.

TABLE 6.—*Easily soluble phosphate in soil in p.p.m. of PO_4 after growing four inbred lines of corn, 30 plants per gallon jar.**

	LA	Mc	Ldg	K 187	Check soil
	0.2375 0.2548	0.2375 0.2189	0.3887 0.3506	0.1968 0.1683	0.5463 0.5830
Av.	0.2454	0.2274	0.3685	0.1814	0.5646

*Harper test for phosphate. Dec. 14 to Jan. 25, 1933.

TABLE 7.—*Thornton test for phosphate in plant tissues of four inbred lines.**

Field soil plus†	K 187		LA		Ldg		Mc	
	Color	Grade‡	Color	Grade	Color	Grade	Color	Grade
N, P	Medium blue	4	Dark blue	5	Blue-green	2	Medium blue	4
N	Green	1	Yellow	0	Yellow	0	Pale blue	2.5
P	Dark blue	5	Dark blue	5	Medium blue	4	Dark blue	5
Check	Blue-green	2	Pale yellow	0	Green	1	Light blue	3

*One plant taken from jar of 10 plants for each line growing in 50% soil + 50% quartz sand. Dec. 15, 1932, to Mar. 13, 1933.

†N = at 150 lbs. per acre (in three applications) of 14% $NaNO_3$. P = at 200 lbs. per acre (after germination) of 20% superphosphate.

‡0 = very low phosphorus supply; 1 = low phosphorus supply; 2 = medium low phosphorus supply; 3 = medium phosphorus supply; 4 = medium high phosphorus supply; and 5 = high phosphorus supply.

TABLE 8.—*Root development in four inbred lines and six crosses.*

	K 187	Mc	Ldg	LA	LA x Ldg	Mc x K 187	LA x Mc	LA x K 187	Mc x Ldg	Ldg x K 187
					Exp. 1.—Grown in Soil, Mar. 28 to May 4, 1933					
Primary roots, length in cm.	21	17	27	10	20	13	7	21	24	18
	12	18	36	19	7	5	23	33	28	26
	11	16	11	37	23	13	27	26	27	14
	12	38	33	32	75	32	24	52	42	30
	7	44	39	36	26	29	22	36	13	15
	20	28	36	13	11	34	19	46	35	2
	50	34	39	50	57	37	71	33	69	60
	37	12	9	13	25	42	43	55	78	48
	49	33	13	41	9	39	49	41	38	22
	31	12	28	9	24	33	70	44	21	40
	22	54	38	27	6	39	45	76	32	93
	16	55	26	33	55	70	29	66	60	75
	19	54	46	49		63	65	20	61	81
	34	63	47			67	49	64	4	47
		18	14			55	7			30
		15				36				
		57				72				
Dry weight in mgm:										
Tops........	1,644	2,320	1,519	1,188	1,526	5,198	3,008	3,979	2,386	3,815
Primary roots	401	560	448	222	349	1,211	504	1,005	297	807
Secondary roots......	247	348	106	61	156	1,093	379	1,408	238	524
Ratio of primary to secondary roots......	1.62: 1	1.60: 1	4.22: 1	3.64: 1	2.22: 1	1.10: 1	1.33: 1	0.71: 1	1.20: 1	1.54: 1

Exp. 2—Grown in Soil, Feb. 7 to Mar. 29, 1933

Primary roots, length in cm.	3.7 6.9 5.7 34.9 22.5 21.1 2.1 53.6 27.3 67.0 34.9 63.6 28.0 28.9 48.0 51.7 52.0 47.0	15.3 35.0 14.7 54.6 66.0 12.0 31.0 19.6 19.0 18.0 11.0 39.0 50.0 54.1 33.2 56.8 34.1 61.8 24.0	29.5 22.4 26.0 12.2 42.4 24.0 11.0 35.4 39.2 47.6 46.5 4.7	58.7 32.1 57.5 48.1 7.2 21.4 22.6 27.2 44.0 14.1 11.2 1.5 2.1 4.0 10.5						
Dry weight in mgm:										
Tops........	1,501	1,496	1,244	1,272						
Primary roots	435	272	369	248						
Secondary roots......	238	179	40	98						
Ratio of primary to secondary roots......	1.82: 1	1.52: 1	9.25: 1	2.53: 1						

Close study of the root types of the four inbred lines and their six crosses indicated that they were as different as the tops and just as easily identified. This held true regardless of the medium in which the plants were grown. The ratio of roots to tops could be modified, but root type was constant. All lines were grown in soil for 6 weeks, and it was found that the dry weight ratio of main primary to secondary branch roots was widely different for the different lines, as shown in Table 8. High ratio of secondary to primary roots was directly related to phosphorus efficiency, with Mc and K 187 distinctly higher than LA or Ldg. Among the hybrids, LA x Ldg showed the lowest ratio. Dominance of the root type ratio of the efficient parent appeared in the other hybrids.

Phosphorus moves very little in the soil, as reported by Overseth (12), which magnifies the importance of a ramifying root system with large absorptive area if a plant is to do well in soils low in phosphorus. Such a root system would also be valuable in absorbing soluble phosphate fertilizers before they become fixed in the soil. This accounts for the good growth of the efficient lines in the basic water cultures whose high iron content favored rapid fixation of the phosphorus.

The dominant genetic factors responsible for root branching may be regarded as a part of the favoroble growth gene complex responsible for hybrid vigor. The favorable growth factors already present in a phosphorus inefficient line, such as Ldg, might conceivably show better response in a genotype with higher phosphorus absorbing ability as would be the case in a hybrid with an efficient line. Testing inbred lines on a low phosphorus medium may prove to be a practical method of predicting relative phosphate requirement of their hybrids. Such a method would be less costly than field tests for this phase of adaptation and should result in more accurate advice to growers on the probable usefulness of new hybrids.

It is apparent that old ideas of corn breeding must be changed as a result of the striking individuality to be found in inbred lines of maize. This individuality is expressed from the tassels to the roots and from germination to maturity. By reason of this, certain inbred lines may respond to peculiarities of a given environment better than open-pollinated varieties.

Efforts to develop varieties of corn fairly well adapted to large areas are probably misdirected. Special-purpose hybrids should be made available, more closely adapted to the needs of specific groups of growers. For some areas this will mean drought-resistant types; for others cold-resistance will be required. Some growers may need to resort to phosphate efficient hybrids; others will demand wind-resistant sorts, especially for machine husking.

Further research to develop hybrids specifically adapted for specific needs can do much to raise the correlation between corn acreage and corn production and is an essential step in any program of corn acreage control.

SUMMARY

1. Tests were made with 24 inbred lines and 23 single crosses of maize to determine the relative amount of growth with various

limitations of phosphorus and nitrogen. These tests were conducted with plants growing in soil, sand and soil, river sand, quartz sand, and water cultures, and growth measured in terms of dry weight of the plant produced at 6 weeks of age with one test based on ear weights. They were made at all times of the year over a period of 2½ years.

2. Many inbred lines behaved very much alike, but a few showed distinct differences when grown with a limited phosphorus supply. Evidence of differential response to a low nitrogen supply was less pronounced.

3. The best determinations of the phosphorus requirement of maize were made on plants growing in water culture solutions, with the proper technic, at levels near the critical limit of growth for this element. Differences between types when grown on soil or sand were slower to appear than with water cultures but showed very good correlation with results in water cultures.

4. Two inbred lines which grew well on low phosphorus and two which grew poorly were chosen for more detailed study with adequate replications. They were found to have a significantly differential response when grown on a medium low in phosphorus. Differences in nitrogen efficiency were not found to be large.

5. The six crosses of the four principal inbreds were studied in the same tests with the parents. Dominance of phosphate efficiency was found, particularly with one of the efficient parents. This dominance was most evident on the first levels of phosphorus deficiency most apt to be encountered in soils.

6. The cross of the phosphate inefficient inbred lines showed no evidence of physiologic stimulation with respect to more effective use of limited supplies of nitrogen and phosphorus.

7. No definite relationship was found between phosphate efficiency and percentage composition of phosphorus in the inbred lines. This applies to total phosphorus. Efficient lines when starved showed a greater supply of inorganic phosphorus in the plant than did inefficient lines.

8. Marked differences in the ratio of secondary or branch roots to primary roots were found among the four lines studied. These differences were inherited and not subject to alteration by the medium in which the plants were grown. A high ratio of secondary to primary roots was found with the phosphate efficient lines and a low ratio with the inefficient ones.

9. The six crosses of the four inbreds all showed increased ratio of secondary to primary roots above the average of the two parents. High ratio of secondary to primary roots appeared to be dominant in the F_1 generation.

10. Dominance of inheritance of branched root type is advanced as a probable cause of phosphate efficiency in the hybrids.

11. Dominance of ability to absorb nutrients more rapidly, resulting from the branched root type, is considered to be one of the favorable growth factors causing hybrid vigor.

12. Use of phosphorus efficient lines is suggested for production of hybrids to be used on soils with low phosphorus supply.

LITERATURE CITED

1. Ashby, Eric. Studies in the inheritance of physiological characters. II. Further experiments upon the basis of hybrid vigor and upon the inheritance of efficiency index and respiration rate in maize. Ann. Bot., 46 : 1007–1032. 1932.
2. Balonesco, G. Sur la rétention de l'acide phosphorique par la matière organique du sol. Ann. Sci. Agron. Française et Entrangere, 47 : 364–383. 1930.
3. Brenchley, W. E. Water culture experiments. Ann. Bot., 43 : 89. 1929.
4. DeTurk, E. E., Holbert, J. R., and Howk, B. W. Chemical transformations of phosphorus in the growing corn plant, with results on two first generation crosses. Jour. Agr. Res., 46 : 121–142. 1933.
5. Eckerson, Sophia M. Influence of phosphorus deficiency on metabolism of the tomato. Contr. Boyce Thompson Inst., 3 : 197–218. 1931.
6. Ford, M. C. The nature of phosphate fixation in soils. Jour. Amer. Soc. Agron., 25 : 134–143. 1933.
7. Gericke, W. F. Salt requirements of wheat at different growth phases. Bot. Gaz., 80 : 410–425. 1925.
8. ————. Bread quality of wheat produced in aqueous culture media. Science, 77 : 229–232. 1933.
9. Harper, Horace J. Determination of the easily soluble phosphorus in soils. Science, 76 : 415–416. 1932.
10. Hoagland, D. R. Relation of the concentration and reaction of the nutrient medium to the growth and absorption of the plant. Jour. Agr. Res., 18 : 73–117. 1919.
11. Hoffer, G. N. Some differences in the functioning of selfed lines of corn under varying nutritional conditions. Jour. Amer. Soc. Agron., 18 : 322–334. 1926.
12. Overseth, Oliver E. Movement of fertilizers in Carrington loam. Jour. Amer. Soc. Agron., 25 : 202–216. 1933.
13. Thornton, S. F. A field and laboratory test on plant material for diagnosing phosphorus deficiencies. Purdue Univ. Agr. Exp. Sta. Bul. 355. 1932.
14. Truog, Emil. Problems in methods of applying fertilizers. Amer. Fert., 71 : 29, 38, 40. 1929.
15. Tueva, O. F. Assimilation of phosphoric acid by barley in a water solution. Bul. Inst. Rech. Biol. et Sta. Biol. Univ. Perm, 6 : 261–276. 1929.

BOOK REVIEW

PLANT BIOCHEMISTRY

By W. E. Tottingham. Minneapolis: Burgess Publishing Co. V + 219 pages, illus. Mimeographed; fabroid cover. 1934. $4.25.

This is a textbook developed as an outgrowth of a course in plant biochemistry given by the author. Although in mimeographed form, it is readable, compact, and offers the possibility of making notes on the back of each page. A good conception of its scope may be secured from the chapter headings which include general aspects of plant biochemistry; the materials of metabolism; photosynthesis of carbohydrates, including the seed and fruit; metabolism of carbohydrates; fat metabolism; metabolism of nitrogen compounds; physico-chemical relation of the plant cell, including a discussion of the cell wall, protoplasm, and buffers; the nature and function of enzymes; chemical aspects of respiration; salt nutrition; and climatic effects in metabolism.

To the worker in agriculture and the practical aspects of plant growth, the book is particularly helpful inasmuch as it carries a background of application to plant production. Climatic and nutritional effects are considered in connection with the more carefully controlled laboratory experiments. A feature of the book is the masterly marshalling of facts, concisely stated, and arranged together with accurate references to the authority for each statement.

While the general arrangement, freedom of literature citations, and occasional introduction of laboratory technic makes this work particularly suitable for the classroom, it will be welcomed by the worker in the general line of agriculture as a means of bringing himself up to date on a subject which is overflowing with literature. (H. B. T.)

AGRONOMIC AFFAIRS

COMMITTEE ON STANDARDIZATION OF FIELD EXPERIMENTS

Following a decision to reinstate the Committee on Standardization of Field Experiments, President R. I. Throckmorton has named the following persons to serve on the new Committee: T. A. Kiesselbach, *Chairman*, R. J. Garber, S. C. Salmon, H. M. Steece, J. W. White, and E. B. Reynolds.

MEETING OF NORTHEASTHERN SECTION OF SOCIETY

About a hundred persons participated in the fourth annual summer meeting of the Northeastern Section of the Society which was held at the New Jersey Experiment Station at New Brunswick June 21 to 23. The meeting consisted chiefly of the inspection of field work at the Experiment Station and on outlying fields and substations. At the business session officers for the ensuing year were elected as follows. H. B. Sprague, *President;* J. A. Bizzell, *Vice-President;* and R. P: Thomas, *Secretary-Treasurer.*

THE PROPOSED VOLUME OF PROCEEDINGS

To date, fewer than a hundred persons have indicated a desire for the publication of a volume containing the papers to be presented at the annual meeting this fall, either in full or in abstract. Those who are interested in such a venture are urged to return the postcard which was enclosed in the August number of the *Journal* in order that the Committee on Publications may have some measure of the wishes of the Society in this matter. Suggestions have been received regarding the name of the volume, and these will receive due consideration should it materialize.

REORGANIZATION OF SOILS WORKERS

A committee named by the Soils Section of the Society at Chicago last fall to study existing soils organizations with the view of setting up a single soil science society in America was instructed to place its findings before all of the members of the American Society of Agronomy. The JOURNAL is glad to cooperate with the Committee by publishing the following report.

REPORT OF COMMITTEE ON REORGANIZATION OF WORKERS IN THE FIELD OF SOIL SCIENCE

This committee was directed to study the constitution and by-laws of the several societies and recommend the necessary steps that must be taken in order to provide for a single association of soil scientists organized on a sectional basis similar to the International Society of Soil Science, and that would preserve insofar as it is possible the desirable features of the present associations. The committee has been unable to formulate any satisfactory plan or to agree on any form of a single association of soil scientists, and accordingly no recommendation for the organization of such an association is presented.

The committee did agree that it would be desirable to establish an American Section of the International Society of Soil Science, which should serve as a means of expressing the opinions and of transacting the necessary business of the American members of the International Society of Soil Science. This American Section is not expected to hold meetings for the presentation of papers, nor for the discussion of scientific work in soils, and is not intended to invade the fields now covered by the American Soil Survey Association, the American Society of Agronomy, or like societies.

A very brief outline of the organization of the American Section of the International Society of Soil Science has been prepared for presentation to the American members of the International Society.

Respectfully submitted,

C. F. SHAW, *Chairman* A. G. MCCALL
W. A. ALBRECHT A. L. PATRICK
J. G. LIPMAN A. M. O'NEAL

NEW SOVIET PUBLICATIONS

We are indebted to Mr. J. W. Pincus, Consulting Agriculturist, 381 Fourth Avenue, New York City, for the following information on recent Soviet publications of interest to agronomists. The All-Union Institute of Plant Industry has published a volume on the distribution of varieties of crops and fruits in Transcaucasia and will follow with similar works dealing with the Ukraine, White Russia, Northern Caucasus, Voronej, etc. The Institute has also issued two works on the organization and methods employed in the breeding of cereals and of fruits and berries. Beginning in 1935, the Institute proposes to publish an agricultural year book which will resemble in many respects the Year Book of the U. S. Dept. of Agriculture, with considerable statistical and other data on the agricultural development of the Soviet Union. Further information on these publications may be obtained from Mr. Pincus.

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DISPLACEMENT OF SOIL SOLUBLES THROUGH PLANT ROOTS BY MEANS OF AIR PRESSURE AS A METHOD OF STUDYING SOIL FERTILITY PROBLEMS[1]

C. W. LAURITZEN[2]

The intake of dissolved substances by plant roots growing in nutrient media is a subject of much scientific interest, but the many investigations on this subject have failed to explain satisfactorily the processes by which soil solubles are taken by plant roots and the relation which the nature and concentration of these soil solubles bears to soil conditions and the growth of plants. What is believed to be a new method of procedure for investigating the plant nutrients of the soil and the selective power of the living plant root is described in the following pages. The data obtained by the use of the method seem to justify its consideration as a means of investigating soil-plant nutritional problems. It is hoped that by its use some of the difficulties connected with research in this field may be lessened.

Acknowledgment is due Paul J. Kramer (3)[3] as the idea for devising this method as a means of studying soil-plant problems resulted from the reading of his article on the absorption of water by the root systems of plants.

Briefly, the procedure followed consisted of growing plants in fertilized and in unfertilized soil. Subsequent to the growing of the plants, the tops were cut off and solution forced from the soil through the plant roots by means of air pressure and collected as it emerged from the stem stubs. In some cases the plant roots were killed with heat before the soil solution was forced through them. The solution was collected in consecutive portions, two to four in number, usually distributed over a period of 48 hours. Each portion of solution collected was measured and later analyzed for phosphorus, potassium, and calcium. Determinations were also made for these elements in the soil and the soil moisture content determined at the time the collection of the solution from the stem stubs was completed.

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[1] Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Journal Article No. 183 (n.s.) from the Michigan Agricultural Experiment Station. A thesis presented to the faculty of the Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication May 2, 1934.

[2] Graduate Assistant. The writer wishes to express his appreciation to Dr. C. H. Spurway for his invaluable guidance and interest shown during the course of this investigation; also to Dr. C. E. Millar and Dr. J. W. Crist for their kindly interest in the work and the helpful suggestions and criticisms they have offered from time to time.

[3] Figures in parenthesis refer to "Literature Cited," p. 819.

GREENHOUSE PROCEDURE

Bean plants were grown in the greenhouse in 2-gallon glazed crocks, each containing the equivalent of 8 kg of oven-dry soil. A Brookston loam soil from the vicinity of Unionville, Michigan, was chosen for the experiment. It had been subjected to field tests on bean fertilization for a period of 2 years. Under field conditions beans did not respond to moderate applications of the fertilizers used. This fact does not seem unusual when it is known that the soil is very fertile, producing good yields of corn, wheat, beets, and alfalfa, as well as beans, without the use of fertilizers, although some of the crops mentioned do respond to fertilizer applications. This soil was tested for soluble plant nutrients using Spurway's method (5). It gave low tests for both phosphorus and potassium, indicating that a plant response could be expected from an application of these elements in commercial fertilizers.

In order to determine, if possible, the amounts of these elements which would be necessary to apply to the soil to make them available in such concentrations as it is expected they should exist in the soil solution of fertile soils, 100-gram samples of the soil were weighed out and increments of phosphorus as $Ca(H_2PO)_4)_2.H_2O$ added in solution with sufficient water to make the soil up to optimum moisture content when the solution was thoroughly mixed with it. The soil thus treated was allowed to stand for 1 day and then tested for phosphorus according to Spurway's method (5). The procedure was repeated, adding increments of potassium as KCl and testing for this element (5). Applications of $Ca(H_2PO_4)_2.H_2O$ equivalent to 750 pounds of P_2O_5 per 1,000,000 pounds of soil gave a high test for phosphorus, and KCl equivalent to 600 pounds of K_2O gave a test of 5 p.p.m. for potassium.

Fertilizer was added to the soil in one-half the number of crocks in which beans were to be planted in the form and at the rate given above. The application was made by mixing the air-dry soil on an oilcloth with a sufficient quantity of a solution of $Ca(H_2PO_4)_2.H_2O$ and KCl to bring the soil to the optimum moisture content. The quantity of potassium added to the soil, as will be seen, based on the tests made on the samples of soil receiving the trial applications, was not great enough to bring the concentration up to what might be considered high or sufficient according to Spurway's method. It would have been necessary to increase the rate of application materially before a much higher test for potassium could have been obtained and it was thought that such an application might result in toxic effects.

In order to have plants of the same age for use in obtaining solution from the soil, planting took place at intervals, one crock containing unfertilized soil and one containing fertilized soil being seeded to beans at the same time. The beans were planted in the crocks, two in a place, in three places in the crock. When the plants began to form the second leaf, if more than one plant existed in a place one was removed so that just 3 plants were allowed to grow in each crock.

APPARATUS AND TECHNIC FOR DISPLACING SOIL SOLUBLES THROUGH PLANT ROOTS

In order to force the solution from the soil into the plant roots and out through the cut stem, it is necessary to subject the solution to a force sufficiently great to overcome the resistance offered to the passage of the solution through the root system plus the force necessary to overcome the retaining force exerted by the soil itself on the solution contained. To effect this condition a chamber capable of holding air under pressure was used. The pressure chamber, as it will be called, was made from a steam pressure cooker. A safety valve and outlet valve in combination were installed in the lid. Three holes about 1 cm in diameter were bored through the lid, equally spaced in the line of a semicircle, and threaded so that they could be closed by screwing in metal plugs. The steam entrance was fitted and connected through a needle valve to an air line which was held at a pressure of 30 pounds per square inch by means of a reducing valve.

Connections were made to the stem stubs of the plants left after the tops were cut off by means of fittings made from rubber tubing. Two pieces of tubing, each about 5 cm long but of different sizes, were used. The smaller sized tubing was pulled part way through the larger sized tubing. The smaller and more flexible tubing, which protruded from the end of the larger tubing, was started on to the stem stub which had previously been greased with vaseline and forced on until the stub extended well up into the heavier tubing. The sizes of the pieces of tubing were usually close to 2/8 and 3/8 inch, respectively, inside diameter, depending on the size of the plant stems. After the connections were made on the stem stubs the crock was placed in the pressure chamber. This being done, delivery tubes made from glass tubing having a diameter of about 0.5 cm were inserted through the holes in the lid of the chamber. The rubber seals, made by boring a hole in rubber cushions used for centrifuge tubes, were placed on the tubes with their concave sides next to the lid. The ends of the delivery tubes were then inserted in the rubber connections, attached to the plants, and the rubber seals on the tubes adjusted so that when the lid to the pressure chamber was in place they were just flush with the surface of the lid. Compressed air, when admitted to the chamber after the lid was secured in placed, exerted a force on the rubber cushions, pressing them against the lid and forming effective seals around the delivery tubes and around the holes in the lid through which the delivery tubes entered the chamber. Stopcock grease was placed on the ground surfaces of the lid and chamber to facilitate a better seal. The ends of the delivery tubes protruding from the holes in the lid of the pressure chamber were fitted into receiving flasks by means of two-hole rubber stoppers. One of the holes in the stopper held the end of the delivery tube and the other served as an opening to prevent any back pressure accumulating (Fig. 1).

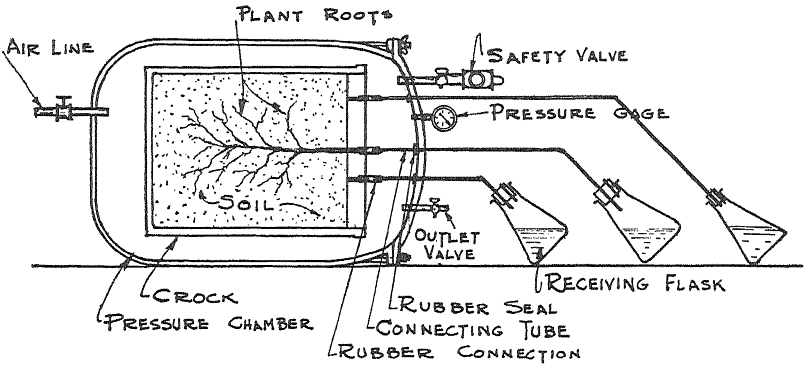

FIG. 1.—Diagram of apparatus, showing one root system.

Bean plants which had reached the stage of maturity when they were setting pods were used to obtain the solution from the soil by the air-pressure method. The tops were cut off about 5 cm above the surface of the soil and the connections made as described previously. Following the period in which the crock containing the soil and roots remained in the pressure chamber, a core of soil was removed through the center of the crock and its moisture content determined. The plant tops which were cut off were weighed and left to dry. The percentage moisture and dry weight were then calculated on an air-dry basis.

The soil solution forced through the plant roots by means of air pressure, designated in the future for the sake of convenience as the solution, was collected over consecutive periods of time, the length of the periods being varied. Usually, the total period was 48 hours. The solution collected from each plant during each of these periods was measured and the volume recorded after which it was returned to the flask in which it was collected, two or three drops of toluene added, and the flask stoppered and set aside.

The roots of the plants in some crocks were killed before the solution was forced through them. This was done by placing the crocks containing the growing plants in a water bath at a temperature of between 80° and 90°C (4). After the soil attained a temperature of approximately 70°C, the crocks were removed from the bath and the soil allowed to cool at room temperature. Cooling under room conditions took about 8 hours. As soon as the soil in the crocks attained room temperature, or as soon afterwards as was convenient, the tops were cut off, the connections made, and the solution obtained in the same way as when the soil was not heated.

In an attempt to see if the changes in the concentrations of the solutions obtained as a result of heating the soil could be affected in another way, 25 ml of ether were added to the soil in one of the crocks about 12 hours before the crock was placed in the pressure chamber.

METHODS OF ANALYSIS

Phosphorus, potassium, and calcium were determined in the soil and in the solutions. Determinations for these elements in the soil were made according to the method of Spurway (5).

Phosphorus was determined in the solutions by the colorimetric method described by Truog and Meyer (6), except in cases where the soil had been heated and the concentrations in the solutions were very small. From 1 to 2 ml of solution, depending on the expected concentration, were diluted to 50 ml, the color developed, and the concentration of the solution determined. Phosphorus determinations on the solution obtained from heated soil were made according to the method of Spurway (5) for testing soils. One ml of the solution obtained by means of the plant roots was used in the determination instead of the 1 ml of soil extract as used in the soil tests.

Potassium was determined according to the method of Kramer and Tisdall (2), with some modification. Two ml of solution or, in some cases, 1 ml of solution and 1 ml of water, were added to a 15-ml centrifuge tube. Two mls of 95% alcohol were added and the cobaltinitrite reagent added with stirring. Centrifuging followed precipitation immediately. The precipitate was washed once with 4 ml of 50% alcohol, recentrifuged, drained, allowed to dry, and titrated in the usual manner.

Calcium in the solution was determined according to the method of Clark and Collip (1). Phosphorus, potassium, and calcium were determined in the soil at the time it was removed from the pressure chamber, according to Spurway's method (5).

EXPERIMENTAL RESULTS

Phosphorus and potassium applied to the soil produced a marked increase in the growth of the bean plants, especially in the early stages. Plants that grew on the unfertilized soil, however, tended to overcome their initial disadvantage as they approached maturity, but never completely overcame their slower start.

The amount of solution collected by means of a plant root over a given period of time as a result of air pressure being applied to the soil varied greatly with the period considered and the individual plant root, with plant roots in the same crock, and to an even greater extent with the plant roots grown in different crocks, ranging from a few ml to more than 100 ml over a 12- to 24-hour period. (Tables 1, 2, 3, and 4.) Heating the soil resulted in a much increased rate of flow and also shortened the time in which the flow was decreased to zero. This fact is evident when the amounts of solutions collected over a given period of time, as recorded in Tables 2 and 4, are compared with the amounts recorded in Tables 1 and 3. The solutions obtained by means of roots in soil which was not subjected to heating were perfectly clear and colorless at the time of collection, but some of the solutions collected, after standing for from 12 to 24 hours, became somewhat turbid. Solutions obtained by means of roots in soil subjected to heating were clear but slightly yellow.

TABLE 1.—*Soil moisture, dry weight of plant tops, ml of solution collected, and concentration of phosphorus, potassium, and calcium in the solutions forced through plant roots from unfertilized soil by means of air pressure over consecutive periods of time.*

Plant No.	Dry weight of plant, grams	Period, hours	Solution collected, ml	Phosphorus, p. p. m.	Potassium, p. p. m.	Calcium, p. p. m.
Crock 1A, Soil Moisture, 15.67%						
1	Total of	0–24	141	6.21	42.05	30.36
		24–48	24	9.65	33.11	50.73
2	three	0–24	147	5.68	41.37	27.32
		24–48	28	7.86	38.41	42.45
3	8.90*	0–24	90	5.00	35.80	17.60
		24–48	16	3.50	156.33†	25.88
Crock 1B, Soil Moisture, 13.70%						
1	4.95	0–24	29	14.16	214.50	145.44
		24–48	7	11.49	480.78†	136.09†
2	3.12	0–24	24	14.10	180.13	82.73
		24–48	5	11.92	448.59†	....
3	5.25	0–24	36	15.25	176.38	91.08
		24–48	7	10.83	337.06†	54.44†
Crock 1C, Soil Moisture, 17.06%						
1	3.67	0–12	38	6.38	94.71	59.21
		12–24	29	6.37	60.28	17.76
		24–48	48	5.68	69.40	17.76
2	6.65	0–12	13	9.09	193.60	120.38
		12–24	17	17.50	145.58	30.59
		24–48	19	16.06	290.26	25.66
3	6.29	0–12	74	6.64	107.08	56.25
		12–24	45	3.94	29.15	24.67
		24–48	56	7.56	76.41	33.55
Crock 1D, Soil Moisture, 13.39%						
1	8.05	0–12	36	17.86	96.59	65.13
		12–24	6	11.42	232.03†	55.26†
		24–48	5	8.96	431.47†	67.10†
2	5.40	0–12	20	9.56	113.25	97.69
		12–24	3	4.25	172.53†	....
		24–48	3	4.19	799.14†	....
3	6.20	0–12	28	14.37	87.34	65.15
		12–24	6	7.32	104.67	45.39†
		24–48	5	3.25	401.82†	49.34†
Crock 3B Soil Moisture, 17.84%						
1	3.55	0–12	92	5.68	67.56	14.85
		12–24	54	4.89	21.34	11.84
		24–48	35	9.49	64.76	30.59

TABLE 1.—*Concluded.*

Plant No.	Dry weight of plant, grams	Period, hours	Solution collected, ml	Phosphorus, p. p. m.	Potassium, p. p. m.	Calcium, p. p. m.
		Crock 3B Soil Moisture, 17.84%				
2.......	2.10	0–12	31	10.55	118.34	25.66
		12–24	17	11.03	111.13	17.76
		24–48	9	10.75	321.23	33.55
3.......	3.60	0–12	46	7.14	63.48	16.78
		12–24	23	8.23	53.88	19.76
		24–48	9	6.70	197.22	35.55
		Crock 3D, Soil Moisture, 17.30%				
1.......	3.95	0– 8	37	10.12	93.39	30.51
		8–24	38	11.52	36.78	26.30
		24–48	19	10.72	133.01	49.44
2.......	5.90	0– 8	47	9.93	56.18	21.04
		8–24	53	12.36	19.70	14.73
		24–48	26	7.97	106.01	41.02
3.......	4.05	0– 8	46	9.17	59.48	17.88
		8–24	54	12.36	16.71	15.78
		24–48	35	7.39	70.72	25.24
		Crock 3E, Soil Moisture, 21.55%				
1.......	3.70	0– 8	35	9.56	116.57	38.92
		8–23	45	6.38	66.56	29.45
		23–48	41	8.01	137.57	41.02
		48–72	21	6.89	134.37	54.70
2.......	3.75	0– 8	42	9.58	132.88	43.13
		8–23	71	5.33	78.88	28.40
		23–48	104	4.37	60.49	17.88
		48–72	71	3.44	59.94	31.56
3.......	4.85	0– 8	58	6.33	95.35	30.51
		8–23	75	5.08	49.73	26.30
		23–48	122	3.52	33.55	13.68
		48–72	90	2.87	36.11	16.83

*Total of three plants.
†Single determination.

Much variation in the concentrations of phosphorus, potassium, and calcium in the solutions are evident from the data in Tables 1 and 3. Nevertheless, it will easily be seen that the phosphorus concentrations in the solutions obtained from unfertilized soil are, on the average, not quite half as high as they are in the solution obtained from soil which received fertilizer applications. Potassium and calcium in the solutions varied more than did phosphorus and were less consistent in any respect. On the average, the concentrations of both potassium and calcium were greater in the solutions obtained by means of the plant roots in fertilized soil than they were in the solutions obtained by means of the plant roots in unfertilized soil. However, the inconsistency was so marked that it does not seem plausible to attach any significance to the average condition.

TABLE 2.—*Soil moisture, dry weight of plant tops, ml of solution collected, and concentration of phosphorus, potassium, and calcium in the solutions forced through plant roots from unfertilized soil by means of air pressure over consecutive periods of time; roots killed by heating soil in crock containing plants to 70° C.*

Plant No.	Dry weight of plant, grams	Period, hours	Solution collected, ml	Phosphorus, p. p. m.	Potassium, p. p. m.	Calcium, p. p. m.
Crock 3A, Soil Moisture, 17.37%						
1.......	4.30	0– 4	54	0.50	4.28	152.37
		4–16	60	0.50	4.71	152.37
		16–40	10	0.50	9.43	134.79
2.......	3.10	0– 4	36	0.50	3.95	157.25
		4–16	45	0.50	6.22	183.62
		16–40	5	0.50	....	189.48
3.......	2.85	0– 4	38	0.50	5.04	141.63
		4–16	60	0.50	5.51	145.53
		16–40	18	0.50	9.23	171.90
Crock 3C, Soil Moisture, 17.42%						
1.......	5.30	0– 3	35	0.50	4.16	159.88
		3–12	42	0.50	3.46	161.98
		12–36	15	0.50	8.15	168.30
2.......	5.10	0– 3	53	0.50	4.23	135.69
		3–12	67	0.50	2.95	161.99
		12–36	38	0.50	3.66	146.21
3.......	4.65	0– 3	41	0.50	2.91	161.99
		3–12	49	0.50	3.27	161.98
		12–36	26	0.50	8.45	164.09

TABLE 3.—*Soil moisture, dry weight of plant tops, ml of solution collected, and concentration of phosphorus, potassium, and calcium in solutions forced through plant roots from soil fertilized with 750 pounds P_2O_5 and 1,200 pounds of K_2O per 1,000,000 pounds of oven-dry soil by means of air pressure over consecutive periods of time.*

Plant No.	Dry weight of plant, grams	Period, hours	Solution collected, ml	Phosphorus, p. p. m.	Potassium, p. p. m.	Calcium, p.p.m.
Crock 2A, Soil Moisture, 16.58%						
1.......	Total of	0–24	127	18.22	72.56	62.81
		24–48	17	16.20	172.71	83.85
2.......	Three	0–24	104	16.50	63.71	51.65
		24–48	15	19.50	150.74	97.36
3.......	15.97	0–24	102	18.15	88.94	45.55
		24–48	13	14.41	239.87	86.96

TABLE 3.—*Concluded.*

Plant No.	Dry weight of plant, grams	Period, hours	Solution collected, ml	Phosphorus, p. p. m.	Potassium, p. p. m.	Calcium, p. p. m.
		Crock 2C, Soil Moisture, 16.79%				
1	9.39	0–12	91	16.86	157.05	47.11
		12–24	44	21.41	148.31	35.59
		24–48	24	22.10	330.21	66.11
2	7.00	0–12	36	32.15	276.58	82.73
		12–24	17	34.72	308.44	57.26
		24–48	14	30.40	436.47	77.95
3	6.99	0–12	84	16.56	125.88	49.20
		12–24	44	17.76	93.92	22.70
		24–48	25	20.16	231.13	55.26
		Crock 2D, Soil Moisture, 17.50%				
1	6.15	0–12	59	13.89	59.18	29.66
		12–24	23	18.15	151.65	58.61
		24–48	15	11.17	446.20	85.95*
2	6.55	0–12	57	13.93	127.44	41.03
		12–24	23	13.05	114.92	48.83
		24–48	6	20.49	467.89	115.25*
3	5.70	0–12	18	30.70	442.17	67.40
		12–24	8	26.88	524.96	56.65*
		24–48	6	15.67	642.09	97.67*
		Crock 4C, Soil Moisture, 17.03%				
1	6.60	0–12	68	18.52	90.49	37.87
		12–24	46	14.81	42.25	27.35
		24–48	42	23.68	105.19	28.40
2	3.55	0–12	32	23.76	91.45	44.18
		12–24	27	15.24	48.35	30.51
		24–48	32	19.35	96.17	17.88
3	5.25	0–12	38	22.36	113.64	43.13
		12–24	22	21.26	95.25	27.35
		24–48	25	32.30	200.77	56.80
		Crock 4D, Soil Moisture, 18.26%†				
1	5.95	0–12	39	15.90	84.10	116.76
		12–24	17	14.95	72.67	117.81
		24–48	7	14.47	307.22	112.55
2	7.70	0–12	91	12.68	72.00	114.65
		12–24	58	12.60	55.66	98.87
		24–48	42	24.46	87.40	66.27
3	2.95	0–12	28	13.51	105.97	225.09
		12–24	15	16.82	193.62	82.05
		24–48	16	23.02	211.14	19.99

*Single determination.
†25 cc of ether added to soil.

TABLE 4.—*Soil moisture, dry weight of plant tops, ml of solution collected, and concentration of phosphorus, potassium, and calcium in solutions forced through plant roots from soil fertilized with 750 pounds P_2O_5 and 1,200 pounds of K_2O per 1,000,000 pounds of oven-dry soil by means of air pressure over consecutive periods of time; roots killed by heating soil in crocks containing plants to 70° C.*

Plant No.	Dry weight of plant, grams	Period, hours	Solution collected, ml	Phosphorus, p. p. m.	Potassium, p. p. m.	Calcium, p. p. m.
Crock 2E, Soil Moisture, 15.70%						
1	8.80	0– 3	96	1.00	8.47	359.06
		3– 7	52	1.00	9.78	334.99
		7–24	33	1.00	18.92	353.83
2	7.47	0– 3	85	1.00	9.84	324.52
		3– 7	46	1.00	8.64	315.10
		7–25	29	1.00	12.20	341.27
3	7.47	0– 3	87	1.00	11.27	362.20
		3– 7	51	1.00	13.24	330.80
		7–25	33	2.00	25.35	359.73
Crock 4B, Soil Moisture, 16.80%						
1	7.05	0– 4	46	0.50	11.24	250.34
		4–12	37	1.00	10.34	239.82
		12–36	34	1.00	10.06	234.56
2	6.85	0– 4	39	0.50	11.50	247.18
		4–12	35	1.00	11.14	249.29
		12–36	33	1.00	11.91	269.27
3	5.60	0– 4	35	0.50	12.01	250.34
		4–12	28	1.00	11.59	247.1
		12–36	20	1.00	12.07	249.2
Crock 4E, Soil Moisture, 16.87%						
1	5.65	0– 3	34	1.00	18.52	295.57
		3–12	51	1.00	17.49	310.30
		12–36	40	1.00	23.91	334.94
2	4.40	0– 3	29	1.00	17.44	315.55
		3–12	40	1.00	17.34	344.05
		12–36	35	1.00	27.07	390.23
3	4.60	0– 3	22	1.00	17.40	312.40
		3–12	34	1.00	16.24	330.28
		12–36	28	1.00	17.03	397.10

TABLE 5.—*Soil tests for phosphorus, potassium, and calcium on soil in crock when removed from pressure chamber.*

	Unfertilized	Fertilized
Reaction	Basic	Basic
Phosphorus	½	High
Potassium	Low	5
Calcium	150	200

An inspection of the data in the same tables, however, reveals a certain consistency in some respects. The concentrations of phosphorus, potassium, and calcium in the solutions obtained by means of plant roots in the same crock were in closer agreement than the concentrations of these elements in the solutions obtained by means of plant roots in different crocks. When the concentration of these elements in the solutions procured by means of a given plant root are followed through the consecutive periods in which these solutions were collected, it is evident that considerable variation exists. However, a change in the concentration of an element in the solution obtained by means of one plant root in a given period was usually accompanied by changes in concentration in the same direction, although not necessarily of the same magnitude in the solutions obtained by means of the other plant roots in the same crock in that period. The more or less parallel fluctuations in the concentrations of phosphorus, potassium, and calcium in the solutions obtained by means of plant roots in the same crock during the time the solutions were being collected were not consistent with regard to the direction the changes in concentration would take.

Soil moisture contents below a certain minimum value did not allow any solution to be forced from the soil into the plant roots. This was the case with one crock. The soil had a moisture content of 13.47% when the crock was removed from the pressure chamber, no solution having been obtained. Also, when crock 2D (Table 3) was placed in the pressure chamber, no solution was obtained, due to the dryness of the soil. But when crock 2D was removed from the pressure chamber, water added to the soil, and the crock replaced in the pressure chamber after a short time was allowed for the soil to absorb the water, solutions were forced from the soil through the plant roots and collected in the receiving flasks. Other soil having a moisture content which approached the minimum made possible the collection of only small amounts of solution by means of plant roots. (See Table 1, crocks 1B and 1D.) The moisture content in the soil in crock 1D is seen to have been lower than it was in crock 2B from which no solution was obtained. However, the moisture content of the soil in crock 1D was determined after the soil was removed from the chamber. Eighty ml of solution is equivalent to the removal of 1% moisture from the soil, and since 112 ml were removed through the plant roots and as there is always a small loss of weight which was not accounted for, it is evident the moisture content was well above the minimum at the time the crock was placed in the chamber. Moisture contents of around 2% above the minimum seemed to be sufficient to allow a maximum rate of flow. A higher water content than this, as nearly as can be judged from the variable results, does not increase the rate of flow materially in the first period but does seem to reduce the rate at which the flow falls from its maximum to zero. This becomes apparent when the amounts of solution collected in the successive periods in Tables 1 and 3 are compared with the amounts of solution collected in the successive periods under crock 3E, Table 1.

Collecting the solutions in portions over consecutive periods rather than as a composite lot was done with the idea of distinguishing between solutions in the roots at the time the tops were removed and that forced in by air pressure later. The data obtained did not indicate any consistent differences in the concentration of phosphorus, potassium, and calcium in the first and subsequent portions collected (Tables 1 and 3). The potassium content increased in the latter periods, but this was not equally true of phosphorus and calcium.

Phosphorus, potassium, and calcium in the solution obtained by means of roots subjected to heating differed greatly from the concentration of these same elements in the solution obtained by means of roots not subjected to heating. Compare the concentrations of these elements recorded in Tables 1 and 3 with those in Tables 2 and 4. As a result of the roots and soil having been heated, the concentration of phosphorus and potassium in the solution is greatly reduced and the concentration of the calcium is much increased.

The addition of 25 ml of ether to the soil in crock 4D (Table 3) was made to see if it might result in increasing the porosity of the root membranes as did killing the roots by heating. The odor of ether was evident in the solutions forced through the roots, but the analysis of these solutions did not show any marked differences in the concentrations of phosphorus, potassium, and calcium from those in the solutions forced through roots in soil to which ether was not added, although the calcium content of the solution was higher, especially in the first period.

SUMMARY

The exact nature of the solution forced from the cut stem stubs of the plants by the application of air pressure is not known. There can be no doubt that it is not unaltered soil solution, nor can it be entirely root sap squeezed out by the pressure applied, inasmuch as the amount obtained in many cases is equivalent in weight to several times the weight of the green plant top cut from the root. To say that the solution obtained is soil solution which is altered as a result of being forced through the plant roots is probably as complete and accurate a statement as can be made.

The solution is altered more by living than by dead roots if it can be assumed that a dilute acid extract of the soil is an index of the soil solution. This can be seen by comparing the concentrations of phosphorus, potassium, and calcium in the soil extract (Table 5) with the concentrations of these elements in the solutions obtained by means of living roots (Tables 1 and 3) and in solutions obtained by means of dead roots (Tables 2 and 4). The fact that the concentrations of phosphorus and potassium are much higher and that the concentration of calcium is much lower in the solutions obtained by means of living roots than the concentrations of these elements in the solutions obtained by means of dead roots would lead one to believe that the condition of the roots as to whether or not they are alive is in some way responsible for the marked differences in concentration in the solutions obtained. Again, since the concentrations of these nutrient elements in the solutions obtained by means of dead roots approach much more closely the concentrations of these elements in the soil extract, it would appear that the living root under the conditions of this experiment retains, to some extent at least, the power of selective intake of nutrients which some believe to be an inherent property of the roots of growing plants.

The better correlation of phosphorus in the solution with fertilizer application than was obtained with potassium and calcium was to be expected inasmuch as the fertilizer application increased the concentration of the phosphorus in the soil extract to a much more marked degree than it did the concentration of potassium and calcium.

The use of air pressure as a means of forcing solution from the soil through plant roots appears to offer a profitable means of investigating soil-plant nutritional problems, although the investigation using this method has not been sufficient to prove its value conclusively or to define its scope and limitations. Thus far the method has been applied only to plants grown in potted soil, but there appears to be no reason why it cannot be applied to plants grown in the field if the soil containing the roots is removed intact and placed in a pressure chamber.

The method could be applied equally well to plants growing in sand or water cultures, and it appears that this procedure offers an opportunity for studying the effects of the various solubles common to nutrient media in regard to their individual and relative concentrations on the intake of the separate elements from solution.

LITERATURE CITED

1. Clark, E. P., and Collip, J. B. A study of the Tisdall method for the determination of blood serum calcium with a suggested modification. Jour. Biol. Chem., 63:461–464. 1925.
2. Kramer, Benjamin, and Tisdall, Frederick F. A clinical method for the quantitative determination of potassium in small amounts of serum. Jour. Biol. Chem., 46:339–349. 1921.
3. Kramer, Paul J. The absorption of water by the root systems of plants. Amer. Jour. Bot., 19:148–164. 1932.
4. Miller, Edwin C. Plant Physiology. New York: McGraw-Hill Book Company. 1931. (Page 370.)
5. Spurway, C. H. Soil testing. Mich. Agr. Exp. Sta. Tech. Bul. 132. 1933.
6. Truog, E., and Meyer, A. H. Improvements in the Deniges colorimetric method for phosphorus and arsenic. Ind. and Eng. Chem., Anal. Ed., 1: 136–139. 1929.

EFFECT OF COMPOSTING ON THE CHEMICAL AND BIOLOGICAL CHANGES IN PEAT AND IN WHEAT STRAW[1]

A. J. Baur[2]

A method for the preparation of artificial manure was devised by Hutchinson and Richards (11)[3] in 1921. The method consisted essentially in composting straw or other organic materials with fertilizer salts and lime. The merits of the product so obtained have been set forth by Albrecht (1), Bottomley (4), Collison and Conn (6), Brown and Smith (5), Manns and Goheen (13), McCool (14, 15), Prianishnikov (17), Halversen and Torgerson (9), and Russell (18).

Several investigators have studied the rate and extent of the chemical and biological changes occurring during the process, but the results of these experiments show considerable lack of agreement. McCool (14, 15), Itano (12), Glomme (8), Valmari (20), and Willis (23) found that nitrogen mineralization in the composts was increased by the addition of fertilizer salts and lime. Wilson and Townsend (24) obtained a high production of nitrates in peat without the use of fertilizers. The experiments of Waksman and Stevens (22) and Vandecaveye (21) showed that the addition of inorganic fertilizers to peat caused no marked change in the number and activity of the micro-organisms. Shunk (19) and Arndt (2), on the other hand, obtained an increase in numbers of micro-organisms by the application of lime and fertilizers to peat. It appears that the lack of agreement may be due largely to differences in the character of the organic materials used.

The object of the following experiments was to obtain further and more definite knowledge concerning the effects of treatment on the decomposition of organic materials, especially peat muck, and to determine the most suitable types for practical modification. The types chosen are representative of the natural deposits found in New York state.

EXPERIMENTAL

METHOD OF PROCEDURE

Two mucks, a peat, and a wheat straw were composted with fertilizer supplements and manure inoculation. Changes in the composted material were followed by determining nitrate and ammonia accumulation, hydrogen-ion concentration changes, and changes in the number of bacteria and fungi.

The straw used was obtained from the 1931 crop of wheat. The mucks and peat were collected in New York state. In this paper they are designated by a local name. The Rose was a woody, dark brown, coarsely granular, well-decomposed muck. The Montezuma was a black, granular, well-decomposed reed and cat-tail muck. The Cicero peat moss consisted of reddish brown, poorly decomposed, fibrous sphagnum peat.

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[2] Special Temporary Fellow in Agronomy. The author wishes to express appreciation to Professor J. A. Bizzell for kindly guidance in the planning and execution of this investigation.

[3] Figures in parenthesis refer to "Literature Cited," p. 830.

A chemical analysis of materials identical to those used is given in Table 1. Approximately 1,000 pounds of moist muck or peat, taking the 12-inch surface layer, were collected for each of the three types. The material was brought to the greenhouse, passed through a quarter inch mesh screen and thoroughly mixed. A definite quantity was then weighed into each of 16 3-gallon earthenware pots. The amount of material weighed out was sufficient to fill the pots to a depth of 9 inches. One hundred pounds of finely cut wheat straw were treated in the same manner as the muck and peat.

TABLE 1.—*Chemical analysis of the materials expressed on dry basis.**

Constituents	Rose (No. 15A)	Montezuma (No. 53A)	Cicero (No. 55A)	Straw
Ash, %	15.90	24.24	5.33	....
Nitrogen (N), %	2.61	2.55	1.46	0.515
Phosphorus (P_2O_5), %	0.38	0.67	0.21	....
Potassium (K_2O), %	0.19	0.21	0.14	....
Calcium (CaO), %	6.09	3.12	0.85	....
Organic carbon (C), %	48.37	42.20	50.37	45.37

*Data, except for straw, taken from Cornell Univ. Agr. Exp. Sta. Bul. No. 537: 1–26. 1932.

Single and combination treatments of calcium carbonate, ammonium sulfate, superphosphate, potassium chloride, and manure inoculum were applied to duplicate composts. The amount of chemicals added in each treatment was based on the dry weight of the material in the pots. For each 1,000 grams of dry material, the following quantities were added: Calcium carbonate, 24 grams; ammonium sulfate, 30 grams; superphosphate, 16 grams; potassium chloride, 12 grams. Ordinary commercial grades of fertilizer salts were ground fine and then mixed with the material in the pots. The manure inoculation was accomplished by the addition and thorough mixing of 200 cc of fresh, concentrated horse manure infusion.

Following the treatments described, sufficient distilled water was added to bring the materials to optimum moisture. The amounts used were as follows: Rose, 233%; Montezuma, 150%; and Cicero, 400%. These percentages were maintained throughout the period of incubation. The straw composts were kept uniformly moist without allowing free water to collect in the bottom of the pots. The experiment was begun September 4, 1931, the pots being allowed to remain in the greenhouse during the period of experimentation. The greenhouse temperature ranged from 60° to 80° Fahrenheit during this period.

METHODS OF ANALYSIS

The pots of muck were sampled with a soil auger. Three borings were made in each pot and the entire amount so obtained was used for analysis. From each pot containing straw a representative quantity was removed by hand.

Nitrate nitrogen was determined by the phenoldisulphonic acid method as outlined by the Association of Official Agricultural Chemists (3) with the modification suggested by Plice (16). The method used for the determination of ammonia was essentially that recommended by Harper (10). Determination of hydrogen-ion concentration was made on a water suspension, using the quinhydrone electrode. The ratio of water to muck or straw was approximately 2.5:1. The plate method was used for obtaining the numbers of bacteria and fungi. Six plates were poured for a single determination. Media 5 and 18, as given by Fred and Waksman (7), were used for bacteria and fungi, respectively. Medium 5 was modified. Beef extract was substituted for sodium albuminate and the reaction was adjusted to pH 6.8 to 7.0 by the use of $CaCO_3$. Medium 18 had a reaction of pH 3.8 to 4.0. An incubation period of 2 and 11 days was allowed for the appearance of fungi and bacteria colonies, respectively. All determinations were made in duplicate on moist samples. The results, however, are expressed on an oven-dry basis.

ACCUMULATION OF NITRATES AND AMMONIA

The effect of composting on nitrate accumulation was studied by determining the amount of nitrates in the composts at the beginning of the experiment and after 1, 3, and 6 months' incubation. Very similar results were obtained with the Rose and Montezuma mucks, as is shown in Table 2. The figures in this and all following tables, except Table 3, are the averaged results from duplicate composts. All of the treatments show large gains in nitrates during the first 30 days. At the end of this period the controls contained approximately 1,000 p.p.m. of nitrates. This figure was increased with continued incubation. The calcium carbonate treatment had very little effect on the nitrates. Both the Rose and Montezuma mucks are high in calcium, (Table 1), and for this reason could not be expected to show much response to the lime treatment. Treatments 2, 5, and 6 showed a large nitrate accumulation as a result of the nitrification of part of the applied ammonium sulfate. The largest amount of nitrates obtained, 12,085 p.p.m. in Rose compost No. 5, is equal to 42.9% of the nitrogen added as ammonium sulfate. Both the rate and total amount accumulated was higher in the treatments receiving complete fertilizer, Nos. 5 and 6, than in the simple ammonium sulfate treatment, No. 2. The addition of manure inoculum caused no response in the Montezuma and only a very slight increase of nitrates in the Rose muck. Treatments 3 and 4 showed a depressing effect on nitrate accumulation which continued during the entire experiment. This effect was most marked in the Montezuma muck. Since calcium carbonate alone had little influence on nitrate production, the depressing effect must have been caused either by the superphosphate or the potassium chloride. The results of a more detailed study concerning the effect of these two fertilizers are presented later.

Nitrate accumulation in the Cicero peat is shown in Table 3. This material did not possess the characteristic of producing nitrates to the same extent as the two mucks previously described. The Cicero

TABLE 2.—*Nitrates in p. p. m. on dry basis in Rose and Montezuma composts at beginning of experiment and after 1, 3, and 6 months' incubation.*

No.	Treatment*	Rose				Montezuma			
		Beginning	1 month	3 months	6 months	Beginning	1 month	3 months	6 months
1....	L	205	1,503	1,940	2,245	364	1,030	1,350	1,553
2....	N	205	2,470	9,782	8,029	364	3,614	5,144	5,573
3....	AP, K	205	1,233	1,444	1,781	364	755	693	906
4....	L, AP, K	205	811	1,288	1,463	364	653	745	798
5....	N, L, AP, K	205	3,343	11,061	12,085	364	5,818	8,658	10,100
6....	N, L, AP, K, M	205	4,187	12,007	11,533	364	6,350	9,646	10,678
7....	M	205	1,206	2,455	2,140	364	1,021	1,217	1,463
8....	Control	205	1,083	2,061	2,051	364	1,088	1,116	1,585

*L = $CaCO_3$, N = $(NH_4)_2SO_4$, AP = Superphosphate, K = KCl, M = Manure.

material had entirely different physical and chemical properties. It was relatively undecomposed and possessed a high acidity, whereas the first two mucks were well decomposed and were considerably less acid. This peat had a low nitrate content at the beginning of the experiment, and comparatively small accumulation took place in the controls. The composts receiving calcium carbonate alone were the only ones to show a consistent nitrate accumulation. One of the composts in treatment 2 also showed a considerable quantity of nitrates, but the duplicate compost showed no significant accumulation. The same is true of treatment 5. A comparison of the last two columns of Table 3 shows that nitrates accumulated at the expense of ammonia. It is striking that nitrification should have proceeded in compost No. 2A because of the very high acidity, namely, pH 3.31.

No nitrates were present in the composts of straw at the beginning of the experiment and only traces appeared during the incubation periods, except in those composts which had received complete fertilizer. The latter had decayed enough by the end of 6 months to allow nitrate accumulation to the extent of 3,000 to 4,000 p.p.m.

Qualitative tests at the beginning of the experiment showed negligible amounts of ammonia in the Rose and Montezuma mucks. The Cicero gave indications of having considerable ammonia. Quantitative determinations of the ammonia in all of the Cicero composts and in the control composts of the mucks were made at the end of 7 months immediately after the determination of nitrates and numbers of micro-organisms. The Rose control composts contained an average of 9.46 p.p.m. ammonia and the Montezuma controls 6.25 p.p.m. Table 6 shows that the amount of ammonia in the supplementary Montezuma composts did not exceed 8.28 p.p.m. Since the Rose muck behaved very similar to the Montezuma, it is safe to assume that little ammonia was present at any time except in those composts receiving ammonium sulfate treatment. The Cicero, however, gave different results. Table 3 shows that a considerable amount of am-

TABLE 3.—*Nitrates in p. p. m. on dry basis in Cicero composts at beginning of experiment and after 1, 3, and 6 months' incubation and p. p. m. of ammonia after 7 months' incubation.*

No.	Treatment*	NO_3				NH_3
		Beginning	1 month	3 months	6 months	
1.....	L	20	113	251	563	25.2
1A...	L	20	144	371	630	30.9
2.....	N	20	85	31	28	7,015.0
2A...	N	20	81	228	312	5,902.4
3.....	AP, K	20	41	54	60	730.2
3A...	AP, K	20	21	29	34	740.5
4.....	L, AP, K	20	21	20	14	607.0
4A...	L, AP, K	20	27	36	31	834.6
5.....	N, L, AP, K	20	81	160	268	5,700.9
5A...	N, L, AP, K	20	26	54	27	6,860.9
6.....	N, L, AP, K, M	20	20	31	16	6,968.3
6A...	N, L, AP, K, M	20	26	35	26	6,976.2
7.....	M	20	22	27	25	491.6
7A...	M	20	23	35	22	569.3
8.....	Control	20	23	35	49	327.9
8A...	Control	20	23	47	33	403.0

*L = $CaCO_3$, N = $(NH_4)_2SO_4$, AP = Superphosphate, K = KCl, M = Manure.

monia was found in all of the Cicero composts, except in Nos. 1 and 1A where it was converted to nitrates. The high amount of NH_3 recorded in treatments 2, 5, and 6 was caused by the ammonium sulfate applied to these composts. Of the remaining treatments, the controls were lowest in ammonia, ranging from 327 to 403 p.p.m. Composts 3 and 4 contained about double the amount found in the controls.

CHANGES IN HYDROGEN-ION CONCENTRATION

The effect of the various treatments on hydrogen-ion concentration is given in Table 4. The data show that lime decreased and the fertilizer salts increased acidity.

CHANGES IN NUMBERS OF BACTERIA AND FUNGI

The numbers of bacteria and fungi per gram of dry compost material were determined after 1, 3, and 6 months of incubation. The data in Table 5 show the number of bacteria in millions and the number of fungi in thousands per gram. Treatments 5 and 6 on the Rose muck were the only ones to show a marked increase in numbers of bacteria for the 1-month period. The figures show that the numbers declined in these as well as in all of the other Rose composts. Such a decrease in numbers indicates that all of the treatments caused some

TABLE 4.—*Hydrogen-ion concentration of the composted materials after 7 months' incubation and of the materials before treatment.*

No.	Treatment*	pH values			
		Rose	Montezuma	Cicero	Straw
1	L	7.41	7.20	4.55	7.44
2	N	4.12	4.15	3.31	4.85
3	AP, K	5.62	5.20	3.32	6.88
4	L, AP, K	6.51	6.66	4.31	7.24
5	N, L, AP, K	4.65	4.46	4.34	5.59
6	N, L, AP, K, M	4.65	4.44	4.34	5.49
7	M	6.01	5.68	3.85	7.63
8	Control	6.04	5.65	3.82	7.50
Before treatment		6.50	5.70	4.00	......

*L = $CaCO_3$, N = $(NH_4)_2SO_4$, AP = Superphosphate, K = KCl, M = Manure.

stimulation during the early part of the incubation period. The cause of this stimulation is not clear. It may have been caused directly by the increased supply of inorganic nutrients added or indirectly through an increase in available carbohydrates or a change in physical condition of the muck due to the addition of fertilizers and handling of the material. The manure inoculation in combination with lime and fertilizer had some effect on the number of bacteria in the Rose composts. Treatments 7 and 8 had practically the same number of bacteria for the three successive determinations. A comparison of 5 with 6 shows that the inoculated composts had more bacteria at the end of 1 month. Taken as a whole, however, manure inoculation showed no significant effect.

The Montezuma composts containing nitrogen fertilizer, namely, Nos. 2, 5, and 6, were the only ones to show an increased number of bacteria. These results, as well as those from Rose treatments 5 and 6, indicate that ammonium sulfate was a factor in regulating the bacterial population.

The most striking feature in the data dealing with the fungi in these two mucks is the reduced numbers found in those composts which showed significant increases in bacteria. Treatments 5 and 6 in the Rose and 2, 5, and 6 in the Montezuma provided conditions very favorable for the growth of bacteria, but according to the data fungi development was far below the level of the controls. This differential development may have been caused by a change in the supply of carbohydrates utilizable by the two kinds of organisms.

The micro-organic population of the Cicero peat was found to be quite different than that of the two mucks. The level of bacterial development was much lower and the fungal level contrastingly higher in the raw, acid Cicero peat. The acid reaction of the Cicero undoubtedly retarded or even prohibited the development of certain types of bacteria, while it did not hinder the growth of fungi.

From the data in Table 5 it is seen that for the first determination all of the treatments in which lime was added, namely, Nos. 1, 4, 5, and 6, gave a higher bacterial count than those in which no lime was

TABLE 5.—*Numbers of bacteria and fungi per gram of dry Rose, Montezuma, Cicero, and straw compost at beginning of experiment and after 1, 3, and 6 months' incubation.*

No.	Treatment*	Bacteria in millions				Fungi in thousands			
		Beginning	1 month	3 months	6 months	Beginning	1 month	3 months	6 months
	Rose Composts								
1....	L	60	77	62	53	59	.....†	66	48
2....	N	60	75	114	32	59	....	56	61
3....	AP, K	60	87	94	73	59	....	68	41
4....	L, AP, K	60	103	95	69	59	....	73	41
5....	N, L, AP, K	60	184	110	131	59	....	23	21
6....	N, L, AP, K, M	60	252	121	135	59	....	25	30
7....	M	60	81	95	75	59	....	74	67
8....	Control	60	67	75	81	59	....	73	40
	Montezuma Composts								
1....	L	71	86	84	90	165	........†	147	151
2....	N	71	128	174	90	165	....	32	96
3....	AP, K	71	94	89	87	165	....	244	213
4....	L, AP, K	71	97	95	84	165	....	261	255
5....	N, L, AP, K	71	169	172	116	165	....	36	17
6....	N, L, AP, K, M	71	132	186	132	165	....	33	42
7....	M	71	100	91	101	165	....	181	169
8....	Control	71	94	74	90	165	....	195	193
	Cicero Composts								
1....	L	16.6	34.5	27.3	15.6	1,230	2,500	1,888	1,498
2....	N	16.6	6.3	15.9	7.9	1,230	5,650	6,415	6,043
3....	AP, K	16.6	8.3	16.5	8.3	1,230	7,950	7,315	5,241
4....	L, AP, K	16.6	61.0	24.3	12.0	1,230	6,450	3,505	2,899
5....	N, L, AP, K	16.6	125.5	47.1	29.1	1,230	4,075	4,515	3,650
6	N, L, AP, K,M	16.6	73.5	60.1	46.5	1,230	3,775	3,245	2,758
7....	M	16.6	20.8	39.5	29.4	1,230	1,765	1,290	1,141
8....	Control	16.6	19.8	28.4	17.5	1,230	2,150	1,715	1,541
	Straw Composts								
1....	L	......	2,572	4,520	3,096	......	550	615	275
2....	N	......	2,224	2,340	1,913	......	800	15,895	12,966
3....	AP, K	......	2,162	3,226	3,201	......	450	1,433	440
4....	L, AP, K	......	2,732	4,011	2,833	......	650	948	480
5....	N, L, AP, K	......	4,558	3,223	2,091	......	3,250	11,060	14,340
6....	N, L, AP, K, M	......	4,326	2,688	1,569	......	6,050	11,710	15,411
7....	M	......	2,572	2,546	3,180	......	600	733	862
8....	Control	......	2,588	3,869	3,566	......	750	899	391

*L = $CaCO_3$, N = $(NH_4)_2SO_4$, AP = Superphosphate, K = KCl, M = Manure.

†No count.

added. The effect of the different treatments was practically eliminated by the end of 3 months. The addition of phosphorous and potassium in treatment 4 and the further addition of nitrogen in Nos. 5 and 6 greatly increased the bacteria over the number shown for calcium carbonate alone, treatment 1. Calcium carbonate, however, was the key to bacterial development in the Cicero peat because treatments 2 and 3 not only failed to show an increase in bacteria but actually showed a depressing effect in the first and last determinations. Manure inoculation had no effect on either bacteria or fungi. All of the fertilizer treatments except lime alone increased the number of fungi several fold.

For the determination of numbers of heterotrophic bacteria in the straw composts it was necessary to make dilutions as high as 1 to 20 million. Using this dilution, the desirable range of 100 to 200 colonies per plate was obtained. The extreme high dilution, however, makes the method less reliable than for lower dilutions as any error in technic is multiplied by a larger factor. Table 5 shows that treatments 5 and 6 on the straw composts were the only ones which caused a pronounced increase in bacterial numbers. The growth of fungi was favored by the use of ammonium sulfate as indicated by the high numbers recorded for treatments 2, 5, and 6.

A comparison of the various materials under consideration shows that the straw was more than 2,000% higher in total micro-organisms, bacteria plus fungi, than the two mucks and the peat. The Rose and Montezuma were quite alike in total numbers, but the Cicero peat averaged much lower, having not more than 20 to 30% of the organism population found in the mucks.

EFFECT OF POTASSIUM CHLORIDE ON NITRATE ACCUMULATION

Attention has already been called to the fact that some treatments containing a mixture of superphosphate and potassium chloride depressed nitrate accumulation (Table 2). In order to obtain further information concerning this effect, Montezuma muck was treated separately with superphosphate and potassium chloride. The quantities of each fertilizer applied were the same as those used in experiments already described. After 40 days incubation, determinations were made of the amount of nitrate and ammonia nitrogen and the numbers of micro-organisms. A qualitative test for nitrites was also made, using Trommsdorff's reagent.

The results of this experiment are given in Table 6. Nitrate accumulation was depressed where potassium chloride was applied alone or with superphosphate. Superphosphate alone, on the other hand, did not have this effect. Thus, the depressing effect can be attributed directly to the potassium chloride. There were from 400 to 500 p.p.m. less nitrates in the compost treated with potassium chloride than in those receiving either superphosphate alone or no fertilizer. The data, however, do not show why there is less nitrate in the potassium chloride treated composts. No nitrites and only small amounts of ammonia occurred in any of these composts. This eliminates the possibility that nitrate reduction took place with an accumulation of these compounds, and it is improbable that free nitrogen was lost under the conditions of the experiment. The decreased nitrates cannot be explained by the fact that this nitrogen was combined in the bodies of micro-organisms. The data show that the number of fungi and bacteria, using both medium 5 and muck extract medium, was practically the same for all of the composts.

TABLE 6.—*Nitrate, nitrite, and ammonia content and number of organisms in Montezuma composts after 40 days incubation.*

Treatment	P.p.m. NO_3, dry basis	Nitrite	P.p.m. NH_3, dry basis	Organisms per gram dry muck		
				Fungi, medium 18	Bacteria in millions	
					Medium 5	Muck extract medium*
Superphosphate..	1,176	None	8.28	118,000	141.0	144.1
KCl............	697	None	5.34	115,000	143.8	139.0
Superphosphate plus KCl......	783	None	7.62	148,000	136.8	163.6
Control.........	1,168	None	8.26	114,000	136.6	142.2

*Composition of muck extract medium: Agar, 12.5 grams; dextrose, 1.0 gram; dipotassium phosphate, 1.0 gram; muck extract, 100 cc; tap water, 900 cc. Reaction pH 7.0.

A tumbler experiment was set up to determine whether potassium chloride in the concentration used created a toxic condition for the development and activity of nitrite- and nitrate-producing organisms. Various potassium salts, as outlined in Table 7, were applied in equivalent amounts of potassium to 100 grams of Montezuma muck. The amount of potassium chloride was proportional to that used in the preceding experiment. Quantitative tests for nitrite- and nitrate-producing bacteria were made 14 and 30 days after the application of the salts. These determinations were made by inoculating a series of 20-cc portions of ammonium sulfate and sodium nitrite media with portions of suspensions using increasingly larger dilutions. The appearance of nitrites and nitrates in the respective solutions gave quantitative indications of the number of bacteria.

TABLE 7.—*Nitrate content in tumbler treatments and dilutions in which nitrite- and nitrate-producing bacteria appeared 14 and 30 days after treating the muck.*

Treatment*	Nitrates after 30 days, p. p. m. NO_3 dry basis	Dilutions in which organisms appeared			
		After 14 days		After 30 days	
		Nitrite bacteria	Nitrate bacteria	Nitrite bacteria	Nitrate bacteria
KCl......	1916	1–100	1–10	1–1,000	1–500
K_2SO_4.....	3263	1–250	1–100	1–2,000	1–15,000
K_2HPO_4...	3666	1–2,000	1–500	1–15,000	1–50,000
Control....	3525	1–250	1–250	1–2,000	1–15,000

*C. P. salts used.

The data in Table 7 show that the potassium chloride treatment depressed nitrate accumulation and decreased the number of nitrite- and nitrate-producing bacteria as compared with the control and with the potassium sulfate and the dipotassium acid phosphate treatments. A close relationship exists between the number of nitrifying organisms and nitrate accumulation. From the meagre amount of data presented, it appears that the chloride form of potassium, in the concentration used, produced a toxic condition for the development and activity of nitrifying bacteria.

SUMMARY

An experiment showing the result of composting two mucks, a peat, and a straw has been described. Fertilizer salts, lime, and manure inoculum were used as supplements. Chemical and biological changes in the variously treated composts were studied by determining the amount of nitrate and ammonia nitrogen and the number of heterotrophic micro-organisms at various intervals. Hydrogen-ion concentration was also determined.

The well-decomposed Rose and Montezuma mucks were not greatly affected by any of the treatments. The use of lime alone caused no significant chemical or biological change. Superphosphate plus potassium chloride with and without lime decreased nitrates, but had no effect on the number of heterotrophic micro-organisms. Some of the composts received ammonium sulfate either alone or with a complete fertilizer. Nitrate accumulation was high in these cases due mainly to the nitrification of part of the applied ammonium sulphate. The use of ammonium sulfate alone or with superphosphate, potassium chloride, and lime temporarily increased the number of bacteria but decreased the fungi. The manure inoculum had very little effect, but any differences noted were in favor of increased nitrates and micro-organisms. The control composts showed a rapid accumulation of nitrates, a low content of ammonia, and large numbers of bacteria and fungi.

An application of lime to the poorly decomposed Cicero peat caused nitrate accumulation. This effect was not demonstrated consistently by any of the other treatments. Lime alone or with nitrogen, phosphorus, and potassium greatly increased the number of bacteria during the first part of the incubation period. All of the treatments except lime alone and manure increased the ammonia content and the number of fungi in these composts.

The application of complete fertilizer with lime hastened the decomposition of straw by immediately increasing the number of micro-organisms. Nitrates accumulated in these composts.

Lime decreased and the fertilizer salts increased acidity in the composts.

Potassium chloride depressed the accumulation of nitrates in the Rose and Montezuma mucks. It proved to be toxic to the development of autotrophic organisms. This effect was not observed when either potassium sulfate or dipotassium acid phosphate were used.

LITERATURE CITED

1. ALBRECHT, W. A. Artificial manure production on the farm. Mo. Agr. Exp. Sta. Bul. 258 : 1–20. 1927.
2. ARNDT, Th. Beitrage zur Kenntnis der Mikrobiologie unkultivierter und kultivierter Hochmoore. Centbl. für Bakt., 2 Abt., 45 : 554–574. 1916.
3. Assoc. Off. Agr. Chemists. Official and Tentative Methods of Analysis. Ed. 2. 1925.
4. BOTTOMLEY, W. B. The bacterial treatment of peat. Jour. Roy. Soc. Arts, 62 : 373–380. 1914.
5. BROWN, P. E., and SMITH, F. B. The production of artificial manure from oats straw under control conditions. Jour. Amer. Soc. Agron., 21 : 310–322. 1929.
6. COLLISON, R. C., and CONN, H. J. Artificial manure from straw. N. Y. Agr. Exp. Sta. Bul. 573 : 1–17. 1929.
7. FRED, E. B., and WAKSMAN, S. A. Laboratory Manual of General Microbiology. 1928.
8. GLOMME, H. Investigations of the ammonia and nitrate production in different types of humus and factors influencing these processes. Norges Landbrukshoiskole, Jan. 1932. (English trans. pages 298–325.)
9. HALVERSEN, W. V., and TORGERSON, E. F. Production of artificial farmyard manure by fermenting straw. Jour. Amer. Soc. Agron., 19 : 577–584. 1927.
10. HARPER, H. J. The determination of ammonia in soil. Soil Science, 18 : 409–418. 1924.
11. HUTCHINSON, H. B., and RICHARDS, E. H. Artificial farmyard manure. Jour. Min. Agr., 28 : 398–411. 1921.
12. ITANO, A. Biological investigation of peat. Jour. Bact., 10 : 87–95. 1925.
13. MANNS, T. F., and GOHEEN, J. N. A preliminary report on muck humus as a fertilizer and carrier of beneficial soil bacteria. Del. Agr. Exp. Sta. Bul. 115 : 1–40. 1916.
14. McCOOL, M. M. Value of peat for mineral soil improvement. Contr. Boyce Thompson Inst., 4 : 245–255. 1932.
15. ———. Use of peat in composts to increase nitrification and plant growth. Contr. Boyce Thompson Inst., 4 : 257–271. 1932.
16. PLICE, M. J. The determination of nitrates in soil containing soluble organic matter. Soil Science, 23 : 213–215. 1932.
17. PRIANISHNIKOV, D. N. The value of peat as a material for the preparation of peat manure and compost. (Translated title.) Trudy. Nauch. Inst. Udobr., 34 : 72–75. 1926. (Exp. Sta. Rec., 58 : 721. 1928.)
18. RUSSELL, E. J. Report on humogen. Jour. Bd. Agr., 24 : 11–20. 1917–18.
19. SHUNK, I. V. Microbiological activities in the soil of an upland bog in eastern North Carolina. Soil Science, 27 : 283–304. 1929.
20. VALMARI, J. Uber die Einwirkung der Dungung und des Wassergehalts auf die Stickstoffumsetzungen im Moor Boden. Abhandl. Agrik. Wiss. Geo. Finland., 10 : 1–74. 1921.
21. VANDECAVEYE, S. C. Effects of stable manure and certain fertilizers on the microbiological activities in virgin peat. Soil Science, 33 : 279–299. 1932.
22. WAKSMAN, S. A., and STEVENS, K. R. Contribution to the chemical composition of peat: V. The rôle of micro-organisms in peat formation and decomposition. Soil Science., 28 : 315–340. 1929.
23. WILLIS, L. G. Nitrification and acidity in the muck soils of North Carolina. N. C. Agr. Exp. Sta. Tech. Bul. 24 : 1–12. 1923.
24. WILSON, B. D., and TOWNSEND, G. R. Some nitrogen relationships in muck soils. Cornell Univ. Agr. Exp. Sta. Mem. 137 : 1–14. 1931.

A STUDY OF THE DEVIATION OF YIELDS FROM DUPLICATE POT CULTURES[1]

FRANKLIN L. DAVIS[2]

Although there is a considerable amount of literature on various phases of experimental plat work with crops and soils, there is but very little literature concerning the average variation in yields from replicated field plats or pot cultures. In the majority of publications in which the experimental error or variation is calculated, the calculated variation is applicable only to the yields from which it is obtained and has but little significance in indicating the degree or magnitude of variation that might be expected in other similar experimental work. It seems that the variation in yields obtained in any given experimental plat or pot culture work should be of a magnitude comparable to that of any other similar experimental work. This should be true if the number and range of yields are sufficient to provide a true and random representation of the population of variations between duplicate or replicate yields. It is the object of this paper to present the results of a study of the deviations of a large number of yields on duplicate pot cultures in the greenhouse.

In the course of a study of the uniformity of the more important agricultural soil types of Alabama, a large number of greenhouse yields from duplicate pot cultures have been obtained. An analysis of the variation between these duplicate pot culture yields has proved of interest, and this analysis is given in this paper with the hope that it may be of general interest and value in giving some information on the nature and magnitude of the average variation to be expected in the yields of duplicate pot cultures in the greenhouse.

EXPERIMENTAL

Only that part of the experimental work that is pertinent to the present discussion will be described here, a more complete description having been given in a previous paper.[3] A number of representative samples of each of the four soil series, Norfolk, Greenville, Hartsells, and Decatur, were collected in the field. In the greenhouse these soils were weighed into 2-gallon glazed pots. Seven different fertilizer treatments in duplicate were used and three crops were grown in succession. The soil was removed after each crop, passed through a screen to remove plant roots, refertilized, mixed, and replaced in the original pot for each successive crop. The first crop grown on each of the groups of soils was Austrian winter peas and the two succeeding crops were sorghum. Only the yields of the sorghum are considered in this paper.

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[2] Assistant Soil Chemist.

[3] DAVIS, FRANKLIN L., and SCARSETH, GEORGE D. Some correlations between crop yields and the readily available phosphorus in soils as determined by Truog's method. Jour. Amer. Soc. Agron., 24 : 909–920. 1932.

The yields in grams of dry matter of the first crop of sorghum from 14 individual pot cultures of each of 22 Norfolk soils, 23 Greenville soils, 22 Decatur soils, and 22 Hartsells soils total 1,246 individual yields in 623 duplications. The yields of the second crop of sorghum likewise total 1,246 individual yields in 623 duplications. Thus, there was available for statistical analysis a grand total of 2,492 individual yields in 1,246 duplications. As an example of the original greenhouse data, the fertilizer treatments and the individual pot yields in grams of oven-dry matter of the first crop of sorghum on the Norfolk soils are given in Table 1. The variation in yields in duplicate cultures of the first crop of sorghum on the Norfolk soils, as shown in Table 1, is representative of the variation between duplicate yields of the other crops on all of the soils.

TABLE 1.—*Fertilizer treatment and yields in grams of first crop of sorghum in oven-dry matter on Norfolk soils.**

Soil No.	N		N, P		N, K		N, P, K		N, K, residual P		N, P, K, residual L		N, K residual P, L	
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13	No. 14
774	13.2	12.8	18.4	19.5	16.4	15.0	23.5	24.6	13.9	18.7	36.7	39.3	35.9	33.3
775	4.4	3.1	8.1	8.0	3.2	2.1	10.3	4.4	6.1	4.8	20.4	20.3	22.0	15.6
776	4.1	6.5	17.4	14.2	6.1	3.1	18.2	9.5	7.7	8.8	22.5	22.1	10.2	11.9
777	0.7	0.5	18.5	18.7	0.5	0.6	26.4	24.8	6.9	7.5	26.5	22.2	6.4	6.6
778	25.3	26.0	33.9	31.1	21.4	23.7	41.4	38.9	26.4	18.4	42.7	46.1	46.0	42.4
779	5.5	7.8	18.5	21.0	6.5	6.3	34.7	32.5	23.7	20.6	41.1	31.9	28.6	25.3
780	4.3	1.4	17.8	16.3	1.2	1.8	17.1	21.5	9.3	9.2	33.8	32.4	27.8	31.4
781	3.4	4.4	17.7	16.9	3.4	4.5	30.9	31.6	22.0	20.4	36.7	34.9	24.4	25.9
782	14.6	11.2	19.3	19.5	12.5	12.9	27.2	29.2	22.0	21.8	30.0	32.6	21.8	20.4
783	18.0	18.6	24.3	16.7	21.4	23.4	38.2	35.7	30.2	33.6	36.1	36.6	30.5	31.7
784	0.4	0.5	14.2	14.6	0.5	0.5	28.1	26.3	10.9	8.1	32.6	31.6	11.0	6.0
785	7.6	7.6	26.1	19.1	9.2	7.4	28.9	29.0	19.6	15.2	33.3	29.5	18.6	22.7
786	11.5	12.1	26.8	29.8	9.6	12.4	32.7	36.1	25.2	23.1	34.7	34.6	22.1	24.9
787	17.6	16.9	21.6	22.8	17.7	18.5	27.5	28.2	23.4	24.1	35.7	37.7	28.8	38.7
788	8.9	6.5	15.5	16.4	11.7	9.1	25.0	25.2	19.1	15.9	33.8	29.6	26.4	21.2
789	9.1	9.5	11.2	16.5	10.7	15.8	33.4	29.6	23.6	21.2	39.8	36.8	30.4	35.3
790	36.3	27.1	38.8	38.5	36.4	33.0	38.7	41.4	43.8	38.0	47.1	43.1	41.3	41.3
791	25.1	21.0	28.4	28.5	24.5	29.5	34.0	34.9	29.0	25.4	44.7	37.0	43.4	35.3
792	10.5	12.4	30.1	25.4	10.1	9.6	35.7	37.1	24.2	23.3	41.2	39.9	36.6	31.9
793	4.0	1.1	11.5	12.1	2.6	4.2	16.7	12.5	7.2	10.2	19.4	28.0	12.3	12.3
794	17.0	11.1	15.4	17.9	28.7	29.2	36.4	31.6	34.4	34.5	34.4	26.8	28.6	26.3
795	19.3	23.3	28.7	27.8	19.9	23.1	35.7	31.1	30.2	29.6	42.3	41.6	37.3	33.0

*Crop yields on the Norfolk soils were obtained by W. W. Pate, formerly assistant soil chemist in charge of the project.

STATISTICAL INTERPRETATION

The question arises as to what method of analysis is to be applied in the study of the variation between these duplicate yields. It is desirable to use a method that will give an evaluation of the average variation in relation to the size of yield. A determination of the mean of the differences between duplicate pot yields and of its probable error, as illustrated by Fisher,[4] gives an average evaluation of the amount of variation between duplicates without regard to the magnitude of yield. It is obvious that the larger the average yield of duplicates, the larger is the *possible variation* between them. This relationship, however, is not linear. The second degree parabola line of non-linear relationship could be fitted by the method of least squares. This expression of the relation of variation between duplicates to the size of yield would be empirical. In addition, the amount of calculations for the large number of observations would be extremely laborious.

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[4] FISHER, R. A. Statistical Methods for Research Workers. London: Oliver and Boyd. Ed. 3. 1930.

In order to determine the relation of variation between duplicates to the size of yield, the data were analysed in class groups. The averages of the duplicate yields were arranged in an array, i.e., in order with regard to size. The plus and minus deviations ($\pm$ d)'s of the duplicates from each average and their squares ($\pm$ d^2)'s were tabulated in corresponding columns. From this tabulated data an average deviation, a standard deviation, and a probable error for any sized group of yields can be readily determined by treating the deviations just as a number of deviations from a single average. A summary of the deviations of duplicates from their respective averages and of the average yields of duplicates by class intervals of 5.0 grams is given in Table 2. A class interval of 5 grams of yield gives convenient class limits with which to work and in a range of yields from 0.1 gram to 75.0 grams, provides 15 classes. The data in Table 2 showing the relation of deviation to size of yield are illustrated graphically in Fig. 1.

It will be noted in Table 2 and Fig. 1 that, in general, both the average deviation and the standard deviation increase as the yield increases, but that there is a slight variation or irregularity from class to class. This is to be expected with so small a number of observations in each class. The average deviations and standard deviations, calculated in Table 2 and plotted in Fig. 1, represent the respective deviations by size groups of duplicate pot yields from their true average yield, as measured by the observed yields included in these calculations. It should be remembered that the average deviation expresses the mean of a group of deviations in just the same manner as the arithmetic mean expresses the average of any group of values. The standard deviation is the square root of the mean of the squares of the deviations. For a fairly normal or regular distribution of observations about the mean, about 68% of the observations will fall within the range from the distance of the standard deviation below the mean to the distance of the standard deviation above the mean.

The deviations of the duplicate yields of both the first and second crop of sorghum on each of the four aforementioned groups of soils were analysed in the manner shown in Table 2 and Fig. 1. There was no significant or uniform difference in the magnitude of the average or standard deviation of duplicates of the first crop of sorghum on any of the four groups of soils. There was, however, a significantly uniform difference between the first crop and the second crop on each of the soil groups. On each group of soils the variation between duplicates of the second crop was greater than that of the first crop. In order to compare the variation between duplicate yields of the first crop with that of the second crop, the yields on all four soil groups

TABLE 2.—*Summary of average yields and deviation of dulpicates of the first crop of sorghum on the Norfolk soils.*

Yield class size	Numner in class (N)	Class yield in grams		$\Sigma (\pm d)$, grams	$\frac{\Sigma (\pm d)}{N}$ (average deviation) grams	$\Sigma (\pm d^2)$, grams	$\frac{\Sigma (\pm d^2)}{N}$, grams	$\sqrt{\frac{\Sigma(\pm d^2)}{N}}$ (standard deviation) grams
		Total	Average					
0– 4.9	13	31.6	2.43	7.6	±0.58	8.32	0.6400	±0.80
5– 9.9	18	140.2	7.79	15.1	± .84	25.53	1.4183	±1.19
10–14.9	16	202.7	12.67	22.1	±1.38	54.43	3.4018	±1.84
15–19.9	18	318.4	17.69	19.5	±1.08	35.51	1.9727	±1.40
20–24.9	25	562.1	22.48	38.7	±1.58	97.19	3.8876	±1.97
25–29.9	19	524.1	27.58	18.3	± .96	28.15	1.4816	±1.22
30–34.9	25	823.8	32.95	43.0	±1.72	112.80	4.5120	±2.12
35–39.9	10	373.1	37.31	15.3	±1.53	45.25	4.5250	±2.13
40–44.9	9	374.6	41.62	13.8	±1.53	33.40	3.7111	±1.93
45–49.9	1	45.1	45.10	2.0	±2.00	4.00	4.0000	±2.00
Total	154	3,395.7	....	195.4	...	444.58	.....	...

were summarized by crops. A summary of the average yields and the deviations of duplicate yields of both the first and second successive crops are given in Table 3. The relation by class groups between the standard deviation and the yield of both the first and second crops is

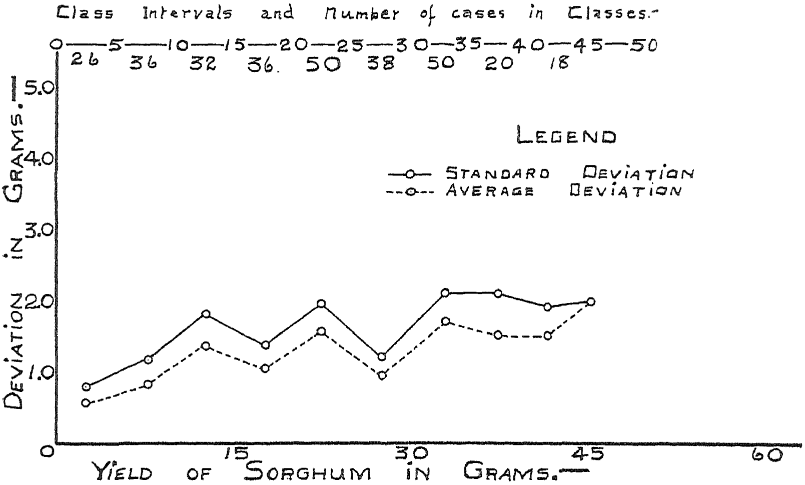

FIG. 1.—Summary by class groups of average deviation and standard deviation of duplicates and yield of the first crop of sorghum on Norfolk soils.

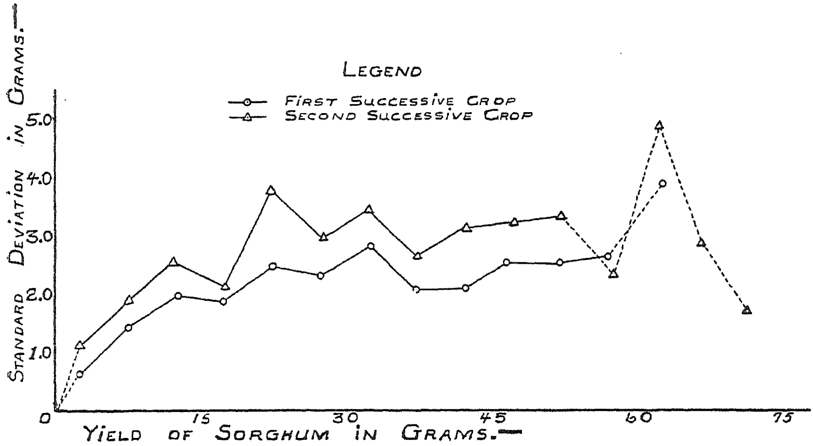

FIG. 2.—Standard deviation of duplicates and average yield of sorghum by class groups.

shown graphically in Fig. 2. In the graph, a broken line is used to connect the co-ordinates of the standard deviation and average yield in those class groups having so small a number of observations that the experimental points do not agree with the general curve of relationship. As the yield increases the standard deviation of the average yields of the first crop approaches a maximum of about 2.5 grams.

TABLE 3.—*A summary by classes of average yields and deviation of duplicate yields of the first and second crops of sorghum on Norfolk, Greenville, Decatur, and Hartsells soils.*

Class size (grams yield)	First successive crop of sorghum						Second successive crop of sorghum					
	Number in class	Average class yield, grams	Average deviation		Standard deviation		Number in class	Average class yield, grams	Average deviation		Standard deviation	
			$\frac{\Sigma(\pm d)}{N}$	Percentage of yield	$\sqrt{\frac{\Sigma(\pm d)^2}{N}}$	Percentage of yield			$\frac{\Sigma(\pm d)}{N}$	Percentage of yield	$\sqrt{\frac{\Sigma(\pm d)^2}{N}}$	Percentage of yield
0– 5........	92	2.6	0.40	15.3	0.64	24.5	122	2.5	0.79	31.2	1.11	43.5
5–10........	108	7.6	1.12	14.7	1.44	18.9	94	7.6	1.43	18.8	1.90	25.1
10–15........	110	12.7	1.51	11.9	1.99	15.7	106	12.1	1.98	16.4	2.55	21.0
15–20........	132	17.4	1.38	7.9	1.89	10.9	124	17.6	1.74	9.8	2.14	12.2
20–25........	152	22.5	1.98	8.8	2.48	11.0	92	22.4	2.86	12.7	3.77	16.8
25–30........	140	27.4	1.66	6.0	2.32	8.5	106	27.7	2.22	8.0	2.96	10.7
30–35........	190	32.6	2.18	6.7	2.82	8.6	108	32.4	2.68	8.3	3.45	10.7
35–40........	116	37.4	1.65	4.4	2.07	5.5	122	37.3	2.09	5.6	2.65	7.0
40–45........	120	42.3	1.62	3.8	2.10	5.0	94	42.5	2.47	5.8	3.13	7.4
45–50........	44	46.5	2.00	4.3	2.54	5.5	98	47.4	2.60	5.5	3.24	6.8
50–55........	26	52.1	2.13	4.1	2.54	4.9	88	52.2	2.47	4.7	3.32	6.4
55–60........	12	57.0	2.40	4.2	2.63	4.6	42	57.6	1.75	3.0	2.33	4.0
60–65........	4	62.7	3.80	6.1	3.90	6.2	34	62.3	3.77	6.1	4.89	7.8
65–70........	...	...	...	...	...	...	14	66.6	2.30	3.5	2.87	4.3
70–75........	...	...	...	...	...	...	2	71.3	1.70	2.4	1.70	2.4
Total for crops	1,246	25.65	1.63	6.34	2.19	8.55	1,246	29.19	2.12	7.25	2.87	9.84

Likewise, the standard deviation of the second crop approaches a maximum of about 3.0 grams. This is true of the class groups having a relatively large number of observations.

Both the average and standard deviation of the yields of both the first and second crop are expressed in terms of percentage of the average yields of their respective class groups in Table 3 and are shown graphically in Fig. 3. The average deviation of the first crop ranges from 15.3% of the average yield in the smaller yields to about 4.0% of the average yield in the larger yields. It is normal to expect the percentage deviation of duplicates to decrease as the average yield increases. The standard deviation of the first crop decreased from 24.5% of the average yield in the smaller yields to about 5.0% of the average yield in the larger yields. The magnitude of these percentage standard deviations compare very favorably with the magnitude of the percentage probable error of cotton yields on small replicated field plats as reported by Ligon.[5] He also stated that, "In field trials, the experimental error due to soil variation may be expected to run around 5%." This agrees with unpublished data obtained at this station. It will be noted that the standard deviation of the yields from pot cultures producing a good growth was about 5% of the average yield.

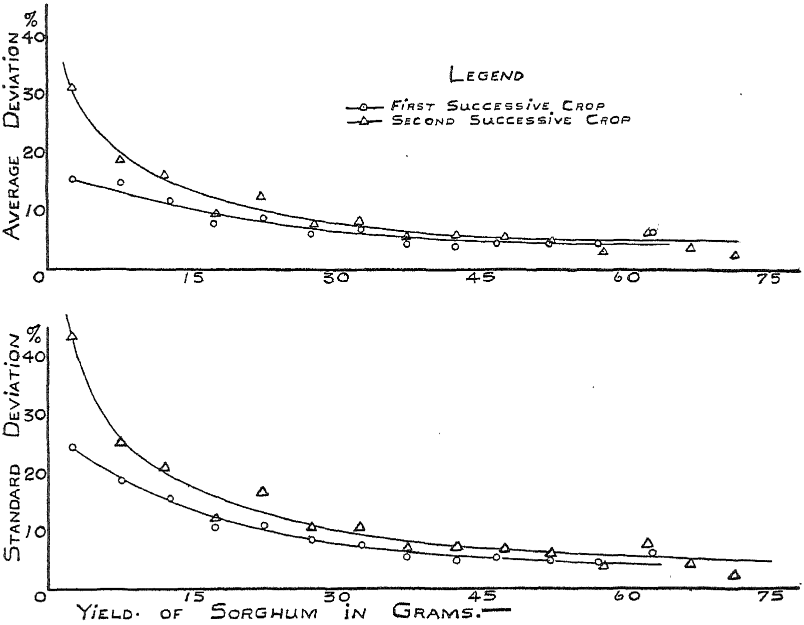

FIG. 3.—Average and standard deviation of duplicates in percentage of yield and average yield of sorghum by class groups.

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[5] LIGON, L. L. Size of plat and number of replications in field experiments with cotton. Jour. Amer. Soc. Agron., 22:689–699. 1930.

In every class group of yields, except one or two in which there were but a small number of observations, the experimental error between duplicate yields was greater in the second successive crop than in the first crop. This is due no doubt to the magnification of the differences between the duplicate pot cultures by the growth of the first crop.

SUMMARY

A study was made of the experimental error of 2,492 yields of sorghum on duplicate pot cultures in the greenhouse. The total number of yields were equally divided in number between two successive crops of sorghum which followed Austrian winter peas on the same soil in pot cultures. A summary of the average yields and of the average deviation and of the standard deviation of the yields by class groups is given.

On the basis of the same size of yields the experimental error between duplicate yields was larger on the second crop than it was on the first. For the first crop of sorghum the average deviation of the duplicate yields from their averages was 6.34% of the average yields and for the second crop 7.25% of the average yield. For the first crop of sorghum the standard deviation of duplicate yields from their averages was 8.55% of the average yield and for the second crop 9.84% of the average yield.

On those pot cultures producing a yield of over 35 grams of dry matter per pot, the average deviation of duplicate yields of the first crop was 4.17% of the average yield and of the second crop 5.11% of the average yield. The corresponding standard deviation of these yields for the first crop was 5.22% of the average yield and, for the second crop, 6.56% of the average yield.

EFFECT OF APPLICATIONS OF SODIUM CHLORATE AND AMMONIUM THIOCYANATE ON SUBSEQUENT SOWINGS OF WHEAT[1]

RUSSELL BISSEY AND O. BUTLER[2]

In the experiments to be described the authors have studied the effect of various rates of application of sodium chlorate and ammonium thiocyanate on the growth of subsequent sowings of wheat. Sodium chlorate renders soil more or less sterile for a considerable length of time, depending on the application given and the specific sensitivity of the crop plant sown.

In Wisconsin (1)[3] land receiving an application of 272 pounds per acre of sodium chlorate in October proved toxic the following season to oats, wheat, and barley, the crops produced by these cereals being very nearly complete failures. Corn also showed injury and produced but two-thirds of a crop. Flax, on the other hand, showed little or no injury.

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[1] Contribution from the Department of Botany, University of New Hampshire, Durham, N. H. Received for publication May 28, 1934.

[2] Research Assistant and Botanist, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p.846.

In England, (2) the toxic effect of a spring application of 200 pounds of sodium chlorate per acre was found to persist 6 months. Of the plants grown following the application of the herbicide, *viz.*, oats, red clover, Italian rye grass, kale, beans, sugar beets, and potatoes, the oats were found most susceptible, the red clover most tolerant. Guthrie and Helms (3) found that the germination of wheat is prevented when a soil contains more than 0.01% of sodium chlorate, and that growth is for a considerable period of time adversely affected by 0.001%. No stimulation of vegetation has been reported as occurring following an application of sodium chlorate.

According to Harvey, ammonium thiocyanate is (4) an active herbicide. He found that when it was applied at the rate of 1,600 pounds per acre, the soil remained sterile for at least 4 months, but that when used at the rate of 800 pounds per acre, the period of sterility was less than 120 days, and when the amount employed was reduced to 320 pounds per acre, the duration of sterility was between 2 and 4 weeks. Following the period of sterility, a stimulation of vegetation occurred.

Obviously, sodium chlorate and ammonium thiocyanate differ in several important respects in their after effects, and the present study was undertaken to determine more precisely the extent of these differences.

METHODS

Six kilograms of sifted and thoroughly mixed air-dry potting soil were placed in each of a number of galvanized iron 10-quart pails adapted for use as pots. In the bottom of each pail a 1-inch drainage hole was bored and a porous earthenware saucer inverted over it. The soil was then placed in the pails and firmly compacted by striking the bottoms on a hard surface until the soil no longer yielded to the pressure of a hand. The water required to saturate the soil in each pail was determined, and 36 pails were selected showing a percentage of saturation within a maximum range variation of 4%. The pails were then allowed to dry spontaneously until they had lost on the average 250 grams more water than was required to give 70% saturation of the air-dry soil when they were divided into the following series of four pots each, except in the case of the checks, when only three pots were used:

Series 1, check
Series 2, ammonium thiocyanate applied at a rate equivalent to 800 pounds per acre.
Series 3, same as 2 but applied at a rate equivalent to 400 pounds per acre.
Series 4, same as 2 but applied at a rate equivalent to 200 pounds per acre.
Series 5, same as 2 but applied at a rate equivalent to 100 pounds per acre.
Series 6, Sodium chlorate applied at a rate equivalent to 800 pounds per acre.
Series 7, same as 6 but applied at a rate equivalent to 400 pounds per acre.

Series 8, same as 6 but applied at a rate equivalent to 200 pounds per acre.

Series 9, same as 6 but applied at a rate equivalent to 100 pounds per acre.

The amount of each salt applied per pot was dissolved in 250 cc of water and the solution poured uniformly over the surface of the soil.

Five days after the herbicides had been applied, 100 seeds of Marquis spring wheat were planted per pot by means of a planting board specially constructed for the purpose. Water was then added in quantity sufficient to bring the total soil moisture up to 70% of saturation, and this percentage was maintained by bringing the pots up to weight periodically. At first the pots were brought up to weight every 48 hours, but as soon as the water loss became considerable, the interval was reduced to 24 hours.

EXPERIMENTAL

Three successive crops of wheat were grown in series 2 to 5 and five successive crops in series 1, 6, 7, 8, and 9, the soil being allowed to stand undisturbed between sowings.

FIRST CROP

Five days after the herbicides had been applied to the soil the wheat was sown. Six days after planting the plants had germinated in the check cultures, but in the sodium chlorate and ammonium thiocyanate series evidences of toxicity were apparent.

In the sodium chlorate series germination was inhibited. In the cultures in which the salt was used at a rate equivalent to 100 pounds per acre, germination was nearly 89% of normal, while in the cultures receiving the equivalent of 800 pounds per acre, it was just under 32% of normal. In the other cultures proportionate decreases were noted. Eventually, some increase in germination occurred, varying for the different cultures fortuitously between 8 and 12%. Ammonium thiocyanate used at rates equivalent to 400 and 800 pounds per acre inhibited germination, but the lower concentrations employed were not injurious. Germination was 48.6% of normal in the cultures receiving 400 pounds per acre and 16.7% of normal when the equivalent of 800 pounds per acre was used. No further increase in germination occurred with time. In fact, in the cultures receiving the equivalent of 400 pounds of ammonium thiocyanate per acre most of the seedlings died, only an average of nine plants per pot surviving at the close of the experiment, and in those receiving the equivalent of 800 pounds per acre all the seedlings were dead 6 days after they had come up.

The general appearance of the plants at the close of the experiment is well illustrated in Figs 1 and 2. The foliage of the plants in the ammonium thiocyanate cultures, irrespective of the vigor of the plants, was darker green than that of the plants in the check cultures, while the foliage of the plants in the cultures receiving sodium chlorate was pale and many of the leaves of the plants growing at the highest concentration were more or less dry in their apical portions.

Twenty-three days after date of planting the crop was harvested. It will be immediately apparent from the data presented in Table 1 that weight for weight, up to an addition equivalent to 400 pounds per acre, sodium chlorate is more toxic than ammonium thiocyanate, but that for applications of 400 pounds or over the latter material becomes more toxic than the former. The germination percentages recorded in the table were taken 6 days after planting and the height measurements 16 days after sowing. Growth as measured by elongation exhibits the same trend as the dry weight data, but the changes are less abrupt. The germination data show that germination, while falling off markedly with increase in concentration of the herbicides, is not as seriously affected as is the growth of the plants.

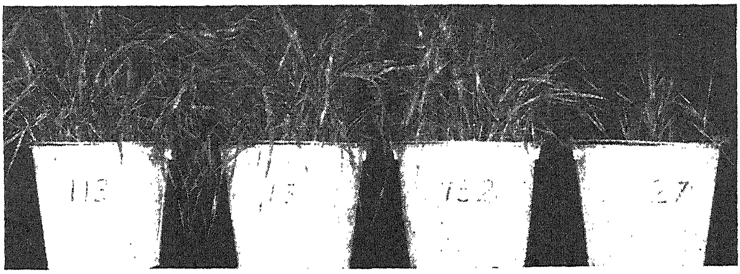

FIG. 1.—Effect of ammonium thiocyanate on the growth of wheat. Reading from left to right: Check; ammonium thiocyanate, 100 lbs. per acre; *ibid.*, 200 lbs.; *ibid.*, 400 lbs.

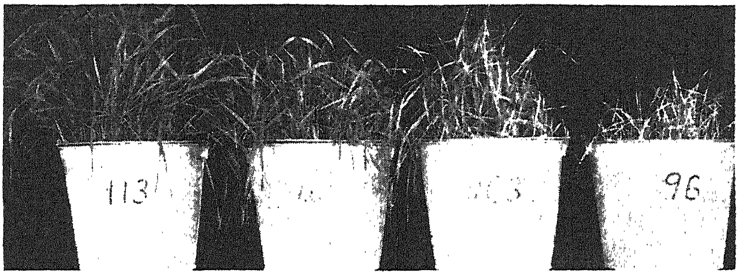

FIG. 2.—Effect of sodium chlorate on the growth of wheat. Reading from left to right: Check; sodium chlorate, 100 lbs. per acre; *ibid.*, 200 lbs.; *ibid.*, 400 lbs.

SECOND CROP

After the first crop had been harvested, the pots were allowed to stand undisturbed 40 days. At the end of the first 2 weeks of fallow interval 1 liter of water was added to each pot and all of the pots were brought up to weight at time of planting. One hundred seeds of Marquis spring wheat were sown per pot, and 37 days after planting the crop was harvested. Sodium chlorate caused injury at all concentrations used. At the lowest concentrations the leaves were pale, the chlorosis being slightly more intense between the veins, while at the higher concentrations the pathognomonic symptoms were even more pronounced. At concentrations equivalent to 400 and 800 pounds per acre growth had practically ceased after 14 days and the plants presented much the same appearance as those of the first crop.

TABLE 1.—*Effect of rate of application of ammonium thiocyanate and sodium chlorate on the growth of wheat.**

	No treatment	Sodium chlorate per acre			
		100 pounds	200 pounds	400 pounds	800 pounds
Germination, %	72.0	64.0	53.0	37.0	23.0
Height of plants, cm	26.6	19.0	15.5	11.5	4.5
Dry weight, rel. nos	100.0	66.6	50.0	15.5	6.1
		Ammonium thiocyanate per acre			
		100 pounds	200 pounds	400 pounds	800 pounds
Germination, %	72.0	78.0	71.0	35.0	12.0
Height of plants, cm	26.6	29.5	26.5	15.0	0.0
Dry weight, rel. nos	100.0	127.8	88.9	6.1	0.0

*Mean temperature from date of planting to date of harvest 21.1°C.

In the ammonium thiocyanate series all the plants were darker green than the check plants, and it was obvious that in the interval that had elapsed since the first crop was grown the concentrations then toxic had become profoundly changed. Instead of toxicity increasing with concentration, stimulation increased with concentration.

The data presented in Table 2 show that 69 days after the herbicides had been applied, the soil meanwhile having grown a crop of wheat followed by a period of fallow, the toxicity of the sodium chlorate was but little changed, the major improvement being in the cultures that had received the equivalent of 100 pounds per acre.

TABLE 2.—*Effect of growing a crop of wheat and of a period of fallow on the persistence of toxicity of sodium chlorate and ammonium thiocyanate.**

	No treatment	Sodium chlorate per acre			
		100 pounds	200 pounds	400 pounds	800 pounds
Germination, %	68.7	58.5	53.8	47.2	45.0
Height of plants, cm	38.2	38.5	31.7	22.2	14.5
Dry weights, rel. nos	100.0	84.0	60.0	22.0	7.6
		Ammonium thiocyanate per acre			
Germination, %	68.7	64.0	61.5	62.5	67.7
Height of plants, cm	38.2	40.0	42.7	42.5	42.0
Dry weights, rel. nos	100.0	106.0	116.0	118.0	156.0

*Mean temperature 20.9°C.

The ammonium thiocyanate cultures, on the other hand, had produced larger crops than the check cultures, although in those which had received the equivalent of 100 pounds per acre of the salt the yield was not as high as in the first crop.

THIRD CROP

After the second crop had been harvested, the pots were allowed to stand undisturbed for 31 days when they were brought up to weight and Marquis spring wheat sown at the usual rate. In the sodium chlorate cultures, seed germination was subnormal at the higher concentrations, but in the ammonium thiocyanate cultures it was supranormal in the higher concentrations. The plants grew normally in the sodium chlorate cultures receiving the equivalent of 100 pounds of the salt per acre, and at no time could the plants be distinguished from those in the check cultures. In the cultures receiving the equivalent of 200 pounds per acre, the foliage was chlorotic and faintly striped and at the higher concentrations pathognomonic symptoms were even more pronounced. All the plants of the cultures in the ammonium thiocyanate series were thrifty, possessed foliage of good color, and stimulation obviously increased with the concentration. Thirty-two days after planting the crop was harvested. The data obtained are presented in Table 3.

TABLE 3.—*Effect of two previous crops and two periods of fallow on the growth of Marquis spring wheat in soil to which sodium chlorate and ammonium thiocyanate had been applied.**

	No treatment	Sodium chlorate per acre			
		100 pounds	200 pounds	400 pounds	800 pounds
Germination, %	64.7	65.0	62.7	47.0	50.0
Height of plants, cm	33.2	36.5	34.2	28.5	16.2
Dry weight, rel. nos	100.0	99.2	81.2	31.2	25.0
		Ammonium thiocyanate per acre			
Germination, %	64.7	62.5	66.5	70.5	73.7
Height of plants, cm	33.2	37.5	35.5	38.5	39.5
Dry weight, rel. nos	100.0	103.0	118.7	131.2	168.7

*Mean temperature 19.2°C.

A glance at the dry weight data shows that the sodium chlorate cultures, which had received the equivalent of 100 pounds of the salt per acre, were producing a normal crop after the lapse of 137 days but that in the case of the higher applications recovery, while consistent, was progressing only slowly. This slowness led us to grow two more crops in the sodium chlorate cultures, but it was not thought necessary to carry the ammonium thiocyanate cultures further since growth still continued vigorously in all of these cultures.

FOURTH CROP

After the third crop had been harvested, the pots were allowed to stand for 14 days when they were brought up to weight and planted.

When the seed germinated, there was some evidence of stimulation in the cultures that had received the equivalent of 100 pounds of sodium chlorate per acre, but inhibition was still noticeable in the cultures that had received the equivalent of 400 and 800 pounds per acre, while the remaining cultures behaved normally. However, after the seedling stage was passed, the growth of the plants in the two lower concentrations paralleled closely that of the check plants, but in the case of the plants in the higher concentrations injury was still pronounced. Thirty-two days after date of planting the crop was harvested. The data obtained are presented in Table 4.

TABLE 4.—*Effect of three previous crops and three fallow periods on the growth of Marquis spring wheat in soil treated with sodium chlorate.**

	No treatment	Sodium chlorate per acre			
		100 pounds	200 pounds	400 pounds	800 pounds
Germination, %..........	63.0	67.0	62.0	56.0	48.0
Height of plants, cm......	25.0	25.0	24.0	20.5	16.0
Dry weight, rel. nos.......	100.0	108.6	91.3	65.8	22.4

*Mean temperature 19.5° C.

It will be seen from consideration of the figures given for dry weight that in the cultures to which sodium chlorate was added at a rate equivalent to 100 pounds per acre, the slight evidence of stimulation noticed when the seed germinated is reflected in the dry weight produced. The cultures to which sodium chlorate had been added at a rate equivalent to 200 pounds per acre, while exhibiting no visible signs of injury during growth, showed a falling off in the dry matter formed of the same order of magnitude as the gain obtained in the cultures that had received the equivalent of 100 pounds per acre. The dry weight produced in the cultures that had received the equivalent of 400 pounds per acre show improvement over the previous crop, but in the 800-pound series there is no diminution of toxicity.

FIFTH CROP

After a period of rest of 13 days following the harvest of the fourth crop, the pots were brought up to weight and Marquis spring wheat again sown at the usual rate. Germination was somewhat irregular and the plants growing in the cultures which had received the equivalent of 400 and 800 pounds of sodium chlorate per acre still showed evidences of injury. In the 400-pound series improvement in growth was noticed, but in the 800-pound series the toxicity remained as marked as in the preceding crop. The general condition of the plants 38 days after planting and just prior to the harvest is illustrated in Fig. 3. The data obtained are presented in Table 5.

A glance at the figures for dry weight shows that the cultures that received the equivalent of 800 pounds per acre of sodium chlorate are still as toxic as they were when the third crop was grown. All the other cultures, however, have shown improvement. When the fourth crop was produced, the cultures that had received the equivalent of 100

TABLE 5.—*Effect of four previous crops and four fallow periods on the growth of Marquis spring wheat in soil treated with sodium chlorate.**

	No treatment	Sodium chlorate per acre			
		100 pounds	200 pounds	400 pounds	800 pounds
Germination, %..........	56.0	66.0	62.0	36.0	46.0
Height of plants, cm......	33.0	32.0	34.0	31.0	22.0
Dry weight, rel. nos......	100.0	114.3	113.0	75.0	25.0

*Mean temperature 18.6° C.

pounds of sodium chlorate per acre were more productive than the check cultures, and they are now even more productive than they were then. The cultures that had received the equivalent of 200 pounds per acre, and which produced 10% less than the check cultures when the fourth crop was harvested, are now 13% more productive. It would appear, therefore, that some slight stimulation may be expected to follow the use of sodium chlorate. One might at first be tempted to ascribe the increased productivity noticed to exhaustion of fertility in the check cultures, but it does not seem that this explanation is warranted, since, over the period of time covered by the last three crops, that is 137 days, the cultures that had received the equivalent of 800 pounds per acre have remained substantially in the same relative relationship to the check cultures, but this could not have happened had the latter grown less productive.

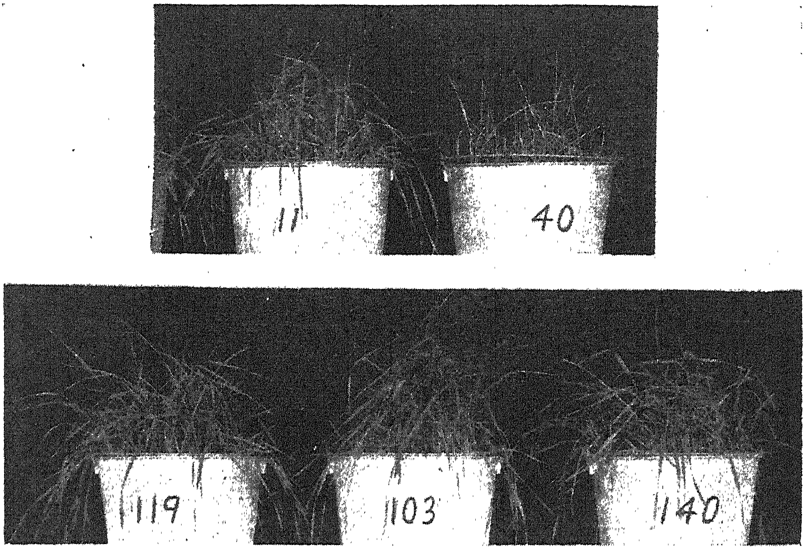

FIG. 3.—Effect of sodium chlorate on the fifth successive crop of wheat. Pot 119, check; pot 103, sodium chlorate, 100 lbs. per acre; pot 140, *ibid.*, 200 lbs.; pot 11, *ibid.*, 400 lbs.; pot 40, *ibid.*, 800 lbs.

SUMMARY

The data presented in the experiment just described show that, in the absence of leaching, cultures that had received, on the one hand, the equivalent of 100 pounds of sodium chlorate per acre and, on the other hand, the equivalent of 200 pounds ceased to be toxic after 131 days and 237 days, respectively, and that at the rate at which toxicity decreased in the cultures that had received applications equivalent to the higher amounts used injury would persist very nearly a year in the case of an application equivalent to 400 pounds per acre and for an application equivalent to 800 pounds per acre very nearly, if not quite, 2 years.

A long period of sterility followed the use of sodium chlorate even when applied in moderate amounts. In the case of ammonium thiocyanate, on the other hand, the period of sterility was short. When applied at a rate equivalent to 100 pounds per acre, there was no period of sterility, and when used at a rate equivalent to 800 pounds per acre marked stimulation of growth occurred after 69 days.

We may infer from these results that sodium chlorate persists for a long time unchanged in the soil, but that ammonium thiocyanate is rapidly decomposed. The rate of decomposition of the ammonium thiocyanate must, in fact, be surprisingly rapid, since the salt itself is weight for weight much more toxic to the higher plants than sodium chlorate.[4]

LITERATURE CITED

1. RUSSELL, H. L. A year's service of research. Wis. Agr. Exp. Sta. Bul. 420. 1931.
2. Miscellaneous notes. Jour. Min. Agr., 38 : 665–667. 1931.
3. GUTHRIE, F. B., and HELMS, R. Pot experiments to determine the limits of endurance of different farm crops for certain injurious substances. Agr. Gaz. New South Wales, 14 : 118–119. 1903.
4. HARVEY, R. B. Ammonium thiocyanate as a weed eradicant. Jour. Amer. Soc. Agron., 23 : 944–946. 1931.

[4] In water culture experiments in which the solutions were renewed every 4 days, ammonium thiocyanate was found to be between 20 and 30 times more toxic to Marquis spring wheat than sodium chlorate.

USE OF PARAFFIN FOR OVERWINTER STORAGE OF SUGAR BEETS[1]

H. L. KOHLS[2]

A common method of storing sugar beets over the winter period, and one which is followed by most breeders of this crop, is to pack the mother beets in boxes, cover the contents with moist sand, and store in a cool root cellar. The sand is moistened when needed, to prevent

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[1] Contribution from the Farm Crops Section, Michigan Agricultural Experiment Station, East Lansing, Mich. Experiment conducted cooperatively with the Division of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication May 26, 1934.

[2] Assistant in Farm Crops. The writer wishes to acknowledge the helpful criticisms received in the preparation of this manuscript, particularly those of E. E. Down.

drying out of the stored roots. Although mother beets keep well when stored in this manner, the labor involved in packing and lifting the boxes, keeping the sand moistened, and the extra space required by the sand tend to make this method of handling stored beets both expensive and inefficient.

Paraffin was used in 1932, in the hope that it would prove as efficient as moist sand for storage purposes, but free from its disadvantages. Such a material to be suitable should maintain, if possible, the sucrose content in the beet and the production of seed, prevent drying out of the stored mother beets, should be light in weight, should be easily applied, and should be comparatively inexpensive. Of the various materials tested in 1933, paraffin most satisfactorily met these requirements. This experiment was more extensive than the one conducted in 1932 and the data obtained therefrom verified those of the preceding year. Only the 1933 data are presented in this paper.

EXPERIMENTS

The plan followed in 1933 was to determine the effect of storage on the sucrose content in the beet and to study the effect that dipping mother beets one, two, and three times into melted paraffin at three different temperatures had on the production of seed per mother beet. The method of applying the paraffin was to have about a 1-inch layer of paraffin floating on top of water maintained at the desired temperature. The details of the various tests are discussed in their respective order of occurrence.

EFFECT OF STORAGE ON SUCROSE CONTENT OF BEETS

An experiment was conducted on one lot of 92 mother beets which in November were carefully cleaned, weighed, and analyzed for percentage of sucrose. Following this, each beet was entirely dipped in melted paraffin heated to about 75° C, reweighed, and stored in a cool cellar where the temperature was held between 32° to 38° during the period of storage. In late March the beets were reweighed and analyzed and percentage loss in sucrose determined. The data are shown in Table 1.

The results given in Table 1 indicate that the loss in weight of mother beets was 7.51%. The loss in total sucrose was only 1.32%, a difference which is not significant. From this it is concluded that proper storage methods are very important in holding the loss in total sucrose to a minimum amount.

LOSS OF MOISTURE IN STORED BEETS

The main purpose of this experiment was to obtain data on the influence of the temperature of the paraffin at the time the beets were dipped, the number of dippings, and the effect which the resulting thickness of the paraffin coating had upon moisture loss per beet and the seed yield per plant. Nine lots of 100 mother beets each and one lot of 175 mother beets were selected for the experiment. The paraffin was applied just before the beets were placed into the storage cellar. Three temperature variables of the paraffin were employed, namely, 55° to 60° C, 70° to 80° C, and 95° to 100° C, the lots of beets being dipped one, two, or three times as shown in Table 2. The mother beets were placed in storage in late November and weighed in late December. All of the beets were stored in open potato crates except the untreated lot of 175 mother beets which was packed in moist sand and used as a control on the paraffin method employed in the comparison of seed production per plant. In late March, all lots of mother beets were reweighed.

TABLE 1.—*The effect of storage upon the average sucrose content of 92 mother beets coated with paraffin.*

	Averages
Weight per beet in November, grams	995.71
Weight of paraffin, grams	18.53
Weight of pulp per beet for analysis, grams	29.03
Weight per beet after analysis and paraffining, grams	985.21
Weight per beet on March 28, grams	911.23
Loss in weight per beet in storage, grams	73.98
Sucrose in fall, %	14.89
Sucrose on March 28, %	16.39
Total sucrose content per beet in fall (995.71 x 14.89), grams	148.26
Total sucrose content per beet on March 28 [(911.23-18.53) x 16.39], grams	146.31
Loss in total sucrose, %	1.95
Sucrose on March 28 (146.31/995.71 original wt. basis), %	14.69
Loss in sucrose, %	0.20

It was found that the size of beet influenced the amount of moisture lost in storage more than did the thickness of the paraffin covering. Small beets have a comparatively large surface area in proportion to their weight and therefore lose a higher percentage of moisture in a given time than large beets. In order that the influence of size might be reduced, a regression line was calculated between the weight of beet in the fall and the loss of weight in storage for each of the nine lots. An arbitrary weight of 1,000 grams per beet was used as a basis of comparison. The data in Table 2 are based upon these calculations.

The data show that in each temperature group the loss of moisture was the smallest in the lot that was dipped three times. The differences are significant and indicate that the thicker paraffin coating in the lots of beets dipped three times was more effective in reducing loss of moisture during storage than the thinner coatings of paraffin afforded in the lots dipped once or twice.

The lots of beets dipped in melted paraffin held at the lower temperature ranges lost less moisture in storage than the lots which were dipped at the high temperature. These differences are significant and show clearly that dipping beets in melted paraffin at lower temperatures is more effective in preventing loss of moisture from the beet.

EFFECT OF DIPPING AND STORAGE OF BEETS ON SEED PRODUCTION PER PLANT

The 10 lots of beets used in the storage experiment were carefully examined before planting, but no trace of deterioration due to low respiration was found. The beets were planted 3 feet apart in duplicate one-row plats, with the rows 3 feet apart. This wide spacing was used to reduce plant competition. Prior to planting, which was made April 15 to 20, the paraffin was removed from the suture of one-half the beets in each lot (group A), while on the remaining half of each lot (group B) the paraffin coating was left undisturbed.

TABLE 2.—*Average loss of moisture of mother beets during the storage period conditioned by the number of dippings given and the temperature of the paraffin applied.*

Lot number	Temperature of melted paraffin, °C	Number of dippings per beet	Average loss of moisture per beet	
			Grams	%
I	55° to 60°	1	30.44 ± 1.04	3.04
II		2	15.88 ± .65	1.59
III		3	11.22 ± .60	1.12
IV	70° to 80°	1	32.41 ± .93	3.24
V		2	21.07 ± .70	2.11
VI		3	14.80 ± .57	1.48
VII	95° to 100°	1	62.45 ± 2.47	6.25
VIII		2	39.97 ± 1.32	4.00
IX		3	34.58 ± 1.22	3.46
		Summary		
		1	41.77 ± .95	4.18
		2	25.64 ± .54	2.56
		3	20.20 ± .49	2.02
	55° to 60°		19.18 ± .46	1.92
	70° to 80°		22.76 ± .43	2.28
	95° to 100°		45.67 ± 1.02	4.57

The beets from both groups started to grow vigorously, but at about 3 or 4 weeks of age those in group B turned very dark green and stopped growing while those in group A continued their growth without interruption. Some of the beets in the B group recovered, but the rest died in about 2 weeks. The paraffin coating was evidently not cracked or was too thick to permit the rootlets to obtain moisture from the soil.

It was observed at harvest time that some of the beets had not produced seed stalks, while others produced seed stalks which had only flowers or immature seeds. Only those beets that had ripe or nearly ripe seeds were harvested.

It was assumed that the loss of moisture in storage, as calculated by the use of the regression line, was a fair index of the thickness of the paraffin coating and that the beets with the thickest paraffin coating lost the smallest amount of moisture. The lots are arranged in Table 3 in the order of the assumed thickness of the paraffin coating. The thickest coating was designated as 1 and the thinnest as 9.

There was a close relationship between the temperature of the paraffin when applied, the number of times the beets were dipped, and the thickness of the paraffin coating. Lots III and VI dipped three times at low and medium temperatures, respectively, had the thickest coatings of paraffin. Lots II and V dipped twice at low and medium temperatures, respectively, were next in order. Lots I and IV dipped once at low and medium temperatures, respectively, were third. Lots IX, VIII, and VII apparently form a group by themselves. These lots were dipped three, two, and one times, respectively, at 95° to 100° C. These lots also lost more moisture than any of the others.

TABLE 3.—*The relationship between the thickness of the paraffin coating removed from suture (group A) and undisturbed (group B) and the temperature at which the paraffin was applied upon the percentage of plants producing seed and average percentage yield of seed per plant.**

Order of thickness of coating	Lot number	Number of times dipped	Temperature ° C	Group A		Group B	
				Percentage plants producing seed	Average seed yield per plant, %	Percentage plants producing seed	Average seed yield per plant, %
1	III	3	55° to 60°	92.0	112.2	38.3	56.7
2	VI	3	70° to 80°	104.2	115.4	67.3	67.6
3	II	2	55° to 60°	97.5	99.4	67.5	68.1
4	V	2	70° to 80°	104.2	115.7	84.2	95.5
5	I	1	55° to 60°	98.7	118.4	98.3	106.3
6	IV	1	70° to 80°	101.5	122.2	86.4	108.8
7	IX	3	95° to 100°	94.2	110.6	71.9	72.8
8	VIII	2	95° to 100°	99.8	85.5	82.5	86.7
9	VII	1	95° to 100°	99.8	93.0	84.6	90.6
10	X	Packed in moist sand		100.0	100.0	100.0	100.0
Probable Error				2.8	9.4	2.8	9.4*

*The value of 100.0 is taken as check. The order of thickness of paraffin coating is designated numerically, *viz.*, 1 is the thickest, 9 the thinnest.

The A group did not show consistent increases in percentage of beets producing seed and average seed yields per plant as the thickness of the paraffin coating decreased. The percentages of beets producing seed in lots IV, V, and VI were the three highest and indicate that dipping the beets in paraffin at 70° to 80° C apparently produced somewhat better results than dipping at higher or lower temperatures. The average seed yields of the A group averaged higher than those of the check lot and are significantly higher than those of the B group. However, lots VIII and VII, which had the thinnest coatings of paraffin, were much lower in average yield of seed than the beets of other lots which had the same number of coatings. It is possible that the thinner coatings were insufficient to protect the beets from excessive moisture loss during the period of storage. Another explanation may lie in the fact that the high temperature at which the paraffin coating was applied may have caused some injury to the beet in the region of the suture where the rootlets develop.

The percentage of beets producing seed in the B group increased in general as the thickness of the paraffin coating decreased in the lots of mother beets dipped at the low and medium temperatures. In lots

IX, VIII, and VII which had been dipped at the high temperature, the percentage of beets producing seed also increased as the thickness of the paraffin coating was decreased, but the percentages were much lower than that of the previous lot, IV. The average seed yield per beet followed the same trend shown for the percentage of beets producing seed. The average yields of seed produced from lots IX, VIII, and VII were consistently below lots V, I, and IV. This indicates that application of paraffin at 95° to 100° C may have had an injurious effect which influenced adversely the percentage of beets producing seed and the average yield of seed per plant.

SUMMARY

The value of paraffin as a coating for mother beets in overwinter storage was studied. The data obtained indicate that:

1. There was no material decrease in the total sucrose content of mother beets dipped in paraffin and stored.
2. A thick coating of paraffin was more effective than a thin coating of paraffin in preventing loss of moisture from mother beets in storage.
3. Paraffin applied to the mother beets at lower temperatures was more effective than paraffin coating applied at a high temperature in preventing loss of moisture.
4. The paraffin coating, although it reduced respiration, did not cause deterioration of the beets.
5. The percentage of beets producing seed and the average yield of seed per plant increased as the thickness of the paraffin coating decreased when the paraffin was not removed from the suture before planting, except in the case of those lots of beets which were dipped in paraffin kept at a temperature of 95° to 100° C.
6. Removing the paraffin coating from the suture of the mother beets at time of planting significantly increased the percentage of beets producing seed and the average yield of seed per plant.
7. Mother beets stored in paraffin gave as satisfactory seed yields as those stored in moist sand when the paraffin coating was removed from the suture at planting time.

EFFECT OF SEED TREATMENTS ON YIELD OF OATS[1]

R. W. LEUKEL AND T. R. STANTON[2]

Increased yields of grain occasionally are reported as a result of treating the seed with certain fungicides. Frequently these increases can be accounted for by the elimination of certain diseases such as smuts. In such cases, increases approximately proportional to the amount of disease eliminated are to be expected unless the treatment is injurious to the seed as well as to the parasite.

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[1] Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

These data were obtained in cooperation with the State agricultural experiment stations and investigators as follows: Illinois, Benjamin Koehler; Iowa, L. C. Burnett and C. S. Reddy; Wisconsin, R. G. Shands; Minnesota, E. R. Ausemus; Indiana, R. M. Caldwell; and New York (Ithaca), W. T. Craig. Received for publication June 8, 1934.

[2] Associate Pathologist, and Senior Agronomist, respectively, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

In other cases, however, seed treatments have been reported to have caused increases in yield that seemingly could not be accounted for by the elimination of disease either because no disease was evident in the plants grown from untreated seed or because it was not sufficient to account for the difference.

If the percentage reduction in yield from untreated seed compared with the yield from treated seed is much greater than the percentage of disease eliminated by treatment, it is likely to be assumed that this is due to stimulation caused by the seed treatment. However, this additional decrease in the yield from untreated seed possibly may be traceable to so-called "latent infection," which does not manifest itself by the usual external sporulation.

REVIEW OF LITERATURE

Flor, Gaines, and Smith (2)[3] have reported the occurrence of systemic infection by bunt which was not apparent in the head but which caused a reduction in yield. Hubbard and Stanton (4) obtained reduced yields from resistant oat varieties grown from smutted seed, although smut infection was not evident. Zade (7, 8) describes latent infection in wheat, barley, and oats and intimates that sporulation should not be an exclusive criterion of infection. Therefore, statements that increased yields following seed treatment are due not to actual disease control but to so-called stimulation should be made with caution.

Some workers, on the other hand, report decreased yields following the use of certain seed treatments even though in some cases the treatments did not seem to affect germination unfavorably and may even have eliminated some disease. Reddy and Burnett (6), working with a number of seed treatments used on several barley varieties, obtained both increases and decreases in yield. In some cases the percentage increases in yield corresponded closely with the percentage increases in relative number of healthy plants. In other cases no such correlation was apparent. Different varieties responded differently to the same treatment. These same workers (1) also obtained in some experiments pronounced increases in the yields of flax following the use of seed treatment and none in other experiments. Disease control was not mentioned.

Koehler (5) used Ceresan and formaldehyde dust on oats and reported increases in yield that apparently could not be attributed entirely to disease control. Treatments applied a day before sowing caused greater increases than those applied a week or more in advance of sowing. When sowing was delayed 3 months after treatment decreased yields resulted.

To obtain additional data on this subject, the writers, in cooperation with workers at several state agricultural experiment stations, carried out seed treatment and yield experiments in 1931 and 1932

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[3] Figures in parenthesis refer to "Literature Cited," p. 857.

A continuation of these experiments was not possible, so such data as were obtained are presented here.

MATERIAL AND METHODS

Smut-free seed of two varieties of oats were furnished by L. C. Burnett, of Ames, Iowa, in 1931, and of three varieties in 1932. The treatments used were Ceresan (ethyl mercury chloride, 1.6% in 1931 and 2% in 1932), Smuttox, Corona oat dust, and Ansul dust, containing, respectively, 4, 5, and 6% of formaldehyde, and the standard wet formaldehyde treatment. The latter was used only in 1931. Smuttox was used in 1931 and Ansul dust in 1932.

The dusts were applied at the rate of 3 ounces per bushel from 1 to 10 days before sowing. The formaldehyde treatment was applied shortly before sowing. In 1931 the seed was sown in 18-foot rows at the rate of 13.5 grams per row at Madison, Wis., Urbana, Ill., and Ames, Iowa. These rows were trimmed to rod lengths at harvest time. In 1932 the seed was sown in rod rows at the rate of 12 grams per row at these stations and at Lafayette, Ind., and St. Paul, Minn. In addition to this, similar sowings were made in 1932 at Ithaca, N. Y. seed of three varieties of oats supplied by W. T. Craig of Ithaca, N. Y., being used. In some cases a nursery drill or hand planter was used to insure uniformity in the depth and rate of seeding. At heading time the plats were examined for smut but practically none was found. Later, the individual rows were harvested and threshed and the yields recorded.

EXPERIMENTAL RESULTS

The results obtained in 1931 are summarized in Table 1. In only one instance was the yield from formaldehyde-treated seed greater than that from untreated seed and this difference was not statistically significant.[4] In the other five tests formaldehyde seems to have caused decreases in yield, two of which were significant. The yields from dusted seed were greater than those from untreated seed in 7 cases and less in 10 cases, none of those differences being apparently significant.

In 1932, in 51 tests, treated seed outyielded untreated seed a total of 30 times, only 3 of these increases being significant (table 2). Untreated seed outyielded treated seed in 20 of the trials, and 3 of these decreases were significant. A grouping of these increases and decreases according to treatment, variety, and station is shown in Table 3.

No marked superiority was displayed by any of the dusts, each one evidently causing one significant increase and one significant decrease in yield. In the experiment as a whole, treated seed outyielded untreated seed by the insignificant margin of 0.6%.

The varieties Iomine and Iowar were about equal in their response to treatment and showed approximately twice as many increases as decreases, while in Sixty-Day the decreases were 3 times the increases.

[4] Probable errors were calculated by the "deviation-of-the mean" method as described by Goulden (3).

TABLE 1.—*Gain or loss in yield from treatment of clean seed of two varieties of oats sown in rod rows at three stations in 1931.*

Station	Rod rows	Yield of check, grams	Increase or decrease in yield from seed treated with							
			Formaldehyde		Ceresan		Smuttox		Corona oat dust	
			Grams	%	Grams	%	Grams	%	Grams	%
					Iomine (2827)*					
Madison....	6	260	—60±17.3	—23.1	—14±18.8	—5.4	1±19.4	0.4	—23±18.5	—8.8
Ames.......	5	265	— 4±11	—1.5	4±11.2	1.5	—10±10.9	— 3.8	1±11.1	0.4
Urbana.....	5	353	34±23.8	9.6	21±23.4	5.9	0±22.6	0	27±23.6	7.6
					Iowar (847)*					
Madison....	6	265	—48±13.5	—18.1	—14±14.4	—5.3	—12±14.5	—4.5	—25±14.1	—9.1
Ames.......	6	218	—17± 6.23	— 7.8	— 8± 6.4	—3.7	— 8± 6.4	—3.7	—12± 6.3	—5.5
Urbana.....	5	422	—50±19.1	—11.8	2±20.3	0.5	2±20.3	0.5	—10±20	—2.4

*Accession number of the Division of Cereal Crops and Diseases.

TABLE 2.—*Gain or loss in yield from treatment of clean seed of varieties of oats sown in replicated rod rows at six stations in 1932.*

Variety and C. I. No.	Station	Rows	Average yield of check, grams	Increase or decrease in yield from seed treated with					
				Ceresan		Formaldehyde dust		Corona oat dust	
				Grams	%	Grams	%	Grams	%
Iomine (2827)	St. Paul....	5	374	—49± 9.9	—13.1	—11±10.4	— 2.9	—37±10.1	— 9.9
	Madison....	5	266	— 3±21.4	— 1.1	51±23.7	19.2	21±22.4	7.9
	Ames.......	5	218	7±18.1	3.2	12±18.2	5.5	— 4±17.6	— 1.8
	LaFayette..	10	203	11±10.8	5.4	7±10.7	3.4	13±10.9	6.4
	Urbana.....	6	317	31± 6.3	9.8	6± 6.1	1.9	7± 6.1	2.2
	Average...		276	— 1	— 0.4	14	5.1	0	0
Iowar (847)	St. Paul.....	5	308	25±17.6	8.1	26±17.7	8.4	31±17.8	10.1
	Madison....	5	387	—19±17.4	— 4.9	—17±17.4	— 4.4	—12±17.5	— 3.1
	Ames.......	5	292	—25±20.7	— 8.6	2±21.7	0.7	— 3±21.5	— 1.0
	LaFayette..	10	217	8± 7.2	3.7	21± 7.4	9.7	10± 7.3	4.6
	Urbana.....	6	348	12±12.1	3.4	10±12.1	2.9	0±11.9	0
	Average...		310	1	0.3	9	2.9	6	1.9
Sixty-Day (165)	St. Paul....	5	324	—34±15.3	—10.5	—26±15.5	— 8.0	—28±15.4	— 8.6
	Madison....	5	349	—46±22.3	—13.2	—70±21.5	—20.1	—29±22.8	— 8.3
	Ames.......	0	...	......	......	......	......	......	......
	LaFayette..	10	197	— 4±12.0	— 2.0	— 2±12.1	— 1.0	4±12.2	2.0
	Urbana.....	10	382	8± 6.2	2.1	— 3± 6.1	— 0.8	8± 6.2	2.1
	Average...		313	—19	— 6.5	—25	— 8.5	—11	— 3.7
Cornellian (1242)	Ithaca......	5	249	— 4± 9.6	— 1.6	18±10	7.2	8± 9.8	3.2
Ithacan (2141)		5	230	5± 6.9	2.2	33± 7.3	14.3	16± 7.0	7.0
Upright (2142)		5	229	5± 9.4	2.2	12± 9.5	5.2	30± 9.9	13.1
	Average...		236	2	0.8	21	8.9	18	7.6

Cornellian was the only one of the three varieties grown at Ithaca that showed any decrease and this was not significant. The other two varieties showed only increases, one in each case significant.

TABLE 3.—*Grouping of increases and decreases in yield of oats following treatment of clean seed in 1932.*

Items of comparison	Trials, number	Number of increases		Number of decreases		Average increase or decrease, %
		Total	Significant	Total	Significant	
			Treatments			
Ceresan	17	9	1	8	1	—.1
Ansul dust	17	11	1	6	1	1.5
Corona oat dust	17	10	1	6	1	1.1
Total	51	30	3	20	3	0.6
			Varieties			
Iomine	15	10	1	5	2	2.0
Iowar	15	9	0	5	0	2.0
Sixty-Day	12	3	0	9	1	—4.0
Cornellian	3	2	0	1	0	3.0
Ithacan	3	3	1	0	0	7.6
Upright	3	3	1	0	0	7.0
Total	51	30	3	20	3	0.6
			Stations			
St. Paul	9	3	1	6	2	—3.4
Madison	9	2	0	7	1	—4.2
Ames	6	3	0	3	0	—0.7
Lafayette	9	7	0	2	0	3.5
Urbana	9	7	1	1	0	2.2
Ithaca	9	8	1	1	0	5.8
Total	51	30	3	20	3	0.6

At St. Paul and Madison the decreases, some of which were significant, outnumbered the increases, while at Lafayette, Urbana, and Ithaca few decreases occurred and none was significant.

DISCUSSION

Experiments of this nature usually are open to certain criticism, and the results, although they may be indicative, cannot be regarded as entirely conclusive. The above experiments were limited to only one or two seasons, the seed was treated in rather small lots and usually several days prior to sowing, and the number of replications and the varieties used were limited. The results obtained, however, do not indicate that the treatment of disease-free seed is profitable. Possibly some of the reported increases in yield from treating apparently clean seed may be due to the elimination of latent infection in the plants, or to the suppression of soil-borne organisms that attack germinating seeds unprotected by seed treatments.

Increases in yield from treated seed over those from untreated seed, when the crop from the latter is diseased, frequently give rise to misleading comparisons between the percentage of disease eliminated and the percentage of increase in yield. For example, if 50% of the plants grown from untreated infected seed are diseased and the yield is 20 bushels per acre, while the crop from treated seed is disease free and yields 40 bushels per acre, the observation commonly made is that, "although the disease eliminated amounted to only 50% the yield was increased 100%", thus intimating that there was an increase in yield over and above that accounted for by the elimination of disease. However, in this case 40 bushels per acre should be considered the basic yield and the 20 bushels per acre difference should be considered as a 50% reduction in yield due to the presence of 50% of disease in the crop. When the yield from untreated seed is used for a base, as the percentage of diseased plants approaches 100, the percentage increase in yield due to disease elimination by seed treatment approaches infinity. But the reduction in yield due to disease cannot exceed 100% of the yield from treated seed. Therefore, the logical comparison should be between the percentage of disease eliminated by treatment and the percentage reduction in yield presumably caused by such disease.

SUMMARY

Results from 2 years' experiments with several varieties of oats grown from clean treated and untreated seed at several stations indicate that, on the whole, seed treatment of clean seed did not cause any consistently significant increase in yield.

LITERATURE CITED

1. Burnett, L. C., and Reddy, C. S. Seed treatment and date of sowing experiments with six varieties of flax. Phytopath., 21 : 985–989. 1931.
2. Flor, H. H., Gaines, E. F., and Smith, W. K. The effect of bunt on yield of wheat. Jour. Amer. Soc. Agron., 24 : 778–784. 1932.
3. Goulden, C. H. Statistical methods in agronomic research. Can. Seed Growers Assoc., Plant Breeders Ser., 2 : 10–12. 1929.
4 Hubbard, V. C., and Stanton T. R. Influence of smut infection on plant vigor and other characters in smut-resistant varieties. In manuscript.
5. Koehler, B. Effect of time and rate of application of seed disinfectants on oats and wheat. Phytopath., 21 : 127. 1931.
6. Reddy, C. S., and Burnett, L. C. Development of seed treatments for the control of barley stripe. Phytopath., 20 : 367–390. 1930.
7. Zade, A. Der latente Pilzbefall und seine Folgeerscheinungen mit Bezug auf Sortenimmunität und Beizwirkung. Fortschr. Landw., 6 : 388–391. 1931.
8. ————. Neue Untersuchungen über den latenten Pilzbefall und seinen Einfluss auf die Kulturpflanzen. Fortschr. Landw., 7 : 529–532. 1932. (Abs. in Rev. Appl. Mycol., 12 : 209. 1933.)

THE ERADICATION OF *LEPIDIUM DRABA*[1]

H. W. HULBERT, H. L. SPENCE, and L. V. BENJAMIN[2]

White top, *Lepidium draba* L., is one of the most serious perennial weed pests in Idaho. The weed has spread rapidly during the past few years and now is distributed widely throughout the irrigated areas. Eradication of white top by the usual commercial control methods has met with little success. In certain counties of the state, applications of as high as 8 pounds of sodium chlorate per square rod have failed to eliminate the weed. The use of such amounts of chemical, even though satisfactory kills were secured, is a prohibitive expense except for small areas.

In view of these facts, extensive experiments have been carried on since 1931 in the Boise Valley, near Meridian. Ten acres of alfalfa land, heavily and unformly infested with white top, were leased for a 4-year period. Six acres of this area were devoted to tillage and smother-crop experiments and the other four to various chemical treatments.

Additional data on the chemical eradication of white top have been secured from experiments in Owyhee and Bear Lake counties. These data show the effectiveness of chemicals under different climatic conditions.

The plats used for all chemical weed work in Idaho were 9 by 30 feet. The chlorate applications were made with a pressure sprayer equipped with suitable spray nozzles and a sediment filter. Calcium chloron and ammonium thiocyanate were applied with the same equipment. A pointed, iron prod, ¾ inch in diameter, was used in punching the holes in the soil for the carbon bisulfide treatments. This chemical was poured into the holes through a half-inch iron pipe with a funnel welded to the upper end. A measuring device, holding the exact amount of chemical needed per hole, was suspended in the funnel.

A 10-foot duckfoot cultivator with 18-inch sweeps and a rotary rod weeder were used to keep down the aerial growth of the white top during the tillage season. The other cultural work was done with the usual farm equipment.

EXPERIMENTAL RESULTS

CHLORATES

Preliminary investigations with white top showed that better kills had been obtained when chlorates were applied in two applications. In order to secure accurate information upon this method, 60 plats were sprayed with initial applications of 1, 2, and 3 pounds of chlorates per rod. Both sodium and commercial calcium chlorate were used on mowed and unmowed areas. Following the initial applications, the plats were divided into three equal parts. The second application was made on two-thirds and the third application on one-third of each plat. Each of the repeat treatments was applied at the rate of 1, 2, 3, 4, and 5 pounds per square rod, respectively. The initial application and 5 pounds per square rod, respectively. The initial application was made on June 12, 1931, the second on June 25, and the third on October 24. This method made it possible to secure the results obtained from a 1-, 2-, and 3-pound initial treatments followed by a repeat spray of 1, 2, 3, 4, and 5 pounds and from two equal repeat applications totaling 2, 4, 6, 8, and 10 pounds of chlorate per rod. Table 1 shows the effect of one repeat spray, while the results of the three applications are shown in Table 2. These tables include the data from both sodium and commercial calcium chlorate sprays applied to mowed and unmowed plats. In several instances 100% kills were secured from the sodium chlorate treatments.

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[2] Agronomist, Extension Agronomist, and Assistant Extension Agronomist, respectively.

TABLE 1.—*Percentage kills of white top obtained from one repeat application of chlorates following varying initial applications.*

Initial application, pounds per square rod	Repeat application, pounds per square rod					
	1	2	3	4	5	Average
1	80.0	88.2	96.2	99.5	99.5	92.7
2	73.8	81.2	82.5	92.5	93.8	84.8
3	71.2	75.0	85.0	93.8	95.0	84.0
Average	75.0	81.5	87.9	95.3	96.1	87.2

These data indicate that a 1-pound initial treatment followed by a 4- or 5-pound repeat application gave best control. Equivalent applications of 1 pound plus 3 pounds, 2 pounds plus 2 pounds, and 3 pounds plus 1 pound gave kills of 96.2, 81.2, and 71.2%, respectively. Similar comparisons of 1 pound plus 4 pounds, 2 pounds plus 3 pounds, and 3 pounds plus 2 pounds produced kills of 99.5, 82.5, and 75.0%, respectively. These data clearly show the effectiveness of a light initial application followed by a heavy dosage when the double treatment method is used.

A comparison of Tables 1 and 2 shows no increase in percentage kill from using the third application except at the lower rates. Moreover, the average percentage kill secured from the three applications is only 3.1% better than that from two applications.

TABLE 2.—*Percentage kills of white top obtained from two repeat applications of chlorates following varying initial applications.*

Initial application, pounds per square rod	Repeat applications, pounds per square rod					
	1 + 1	2 + 2	3 + 3	4 + 4	5 + 5	Average
1	80.0	91.2	94.8	97.0	97.0	92.0
2	76.2	81.2	93.8	95.0	95.0	88.2
3	83.8	87.5	92.5	93.8	96.0	90.7
Average	80.0	86.6	93.7	95.3	96.0	90.3

The ineffectiveness of continued heavy treatments possibly may indicate the development of resistance to the chemical by the plants left unkilled. In many instances numerous plants show varying degrees of chlorate injury, but eventually recover. Such plants are difficult to kill by subsequent dosages of chemical. In several sections of Idaho applications of chlorate over a 3- or 4-year period, totaling 25 pounds per square rod, have failed to kill scattering plants. Similar observations have been noted with other species of perennial weeds with creeping roots. Willard (8)[3], under dry soil conditions in Ohio, found that it took nearly as much chlorate to kill sprouts that recovered after spraying as to kill unsprayed plats.

Late fall chemical treatments have proved generally effective in the control of perennial weeds in Idaho. Numerous other investigators have secured satisfactory kills from fall applications. Megee (5), under Michigan conditions, found that chlorates were much more effective on quack grass when applied in the fall. Sampson and Parker (7), working with St. Johnswort, found that chlorates gave best results when applied in fall or early spring. Aslander (1) killed Canada thistles by applying 200 kilograms of sodium chlorate per hectare as dry salt on the ground in late autumn. In Iowa a 3-year study by Loomis, Bissey, and Smith (4) indicates that sodium chlorate may be more effective applied to roots rather than to aerial portions of the plant. Woodman and Jones (9), working in England, believe that chlorates, due to the length of time usually elapsing between application and visible weed killing effect, seem to act through the soil.

The results of single fall applications of chemical made October 24 in the Boise Valley are shown in Table 3. Calcium Chloron and ammonium thiocyanate were of little value in white top eradication. Sodium and commercial magnesium chlorates produced better kills than commercial calcium chlorate. Similar and equally effective results were secured from these chemicals applied to white top in the rosette stage on October 13 in Bear Lake County.

TABLE 3.—*Effectiveness of October chemical treatments upon control of white top.*

Rate of application, pounds per rod	Percentage kills from various chemicals				
	Sodium chlorate	Commercial calcium chlorate	Commercial magnesium chlorate	Ammonium thiocyanate	Calcium choron
2	85	80	60	50	......
3	85	80	80	80	None
4	90	80	95	80	None
5	95	85	95	80	None
6	100	95	100	85	None
7	......	....	......	....	None

CARBON BISULFIDE

Carbon bisulfide has been used quite extensively in irrigated areas of Idaho for the eradication of small weed patches and in "clean-up" work. This chemical probably was used first as a weed killer in

[3] Numbers in parenthesis refer to "Literature Cited", p. 863.

California. In 1923, Barnum (3) recommended the application of carbon bisulfide in 4-ounce doses in holes 18 inches deep and 3 feet apart each way as effective in the control of wild morning glory. A later California recommendation made by Ball, Madson and Robbins (2) suggests the use of 20-inch rows with the holes 24 inches apart in the row. Rogers and Hatfield (6) recommend the application of carbon bisulfide in holes 2 feet apart each way, using 2 ounces of the chemical in each hole.

A series of plats of white top were treated with carbon bisulfide at various rates, depths, and spacings. These results are shown in Table 4. Apparently, 2-ounce doses applied to a depth of 6 or 8 inches at 18- to 20-inch intervals are most satisfactory for eradicating white top. Carbon bisulfide is effective only in very moist soils. Usually, infested areas are irrigated just previous to the application of the chemical.

TABLE 4.—*Effect of rate of application, spacing, and depth of application of carbon bisulfide upon control of white top.*

Rate of application, ounces per hole	Spacing, inches	Depth of application, inches	Kill, %
1.0	12	8	95
	14	8	95
	16	8	95
	18	8	90
1.5	18	8	98
2.0	18	8	100
	20	8	100
	24	8	98
	18	6	100
	20	6	100
	18	8	100
	18	10	98
	18	12	96
	18	14	92
	20	10	98
	20	12	96
	20	14	98
	22	10	98
	22	12	98
2.5	24	8	96
3.0	30	8	95

TILLAGE EXPERIMENTS

Large infestations of white top cannot be eradicated economically by the use of chemicals, therefore an effective and comparatively inexpensive method must be developed if successful weed control programs are to be promulgated in badly infested areas. Probably cultivation is the logical method for the eradication of such infestations. Tillage practices in order to be used generally must be effective and of comparatively short duration.

The tillage experiments on white top were carried on in the Boise Valley over a 2-year period. During that time almost complete eradication was obtained on the bare tilled areas. The few remaining plants could be eliminated easily by "spotting" with carbon bisulfide.

The tillage method used consisted of early, deep plowing followed by sufficiently frequent cultivation with a duckfoot or rotary rod weeder to keep down all green growth. After plowing the subsequent cultivations should be 4 to 5 inches deep. During the first 6 to 8 weeks it was necessary to cultivate about every 5 days. Later in the season the tillage interval decreased considerably and finally terminated the first season in early October. All live roots were eliminated from the surface 8 inches of soil by the first year's work.

A second plowing during midsummer greatly facilitated eradication. On the areas where the rotary rod weeder was used a second plowing was essential, otherwise the weeder packed the soil so firmly that effective elimination of the top growth was impossible.

Table 5 shows the hours of labor required to keep down the aerial growth of white top on the 6-acre area for the 2-year period. These data would vary somewhat with the width of the tillage implements used. In this experiment 10-foot tillage equipment was used.

TABLE 5.—*Hours of labor required to keep down top growth on 6-acre area of white top.*

Month	Hours of labor	
	Man	*Horse*
First Season		
May	80	261
June	28	110
July	52	189
Aug	16	64
Sept	22	88
Oct	10	40
Total	208	752
Acre ave	34.6	125.3
Second Season		
Apr	13	52
May	22	66
June	18	54
July	33	96
Aug	5	20
Sept	33	99
Oct	14	42
Total	138	429
Acre ave	23.0	71.5
2-year total	346	1,181
2-year acre ave	57.6	196.8

The first season's tillage required 60.1% of the man labor and 63.7% of the horse hours. The acre cost for the 2-year period, assessing the man and horse hours at 30 and 5 cents, respectively, was $27.12. The chemical cost for eradication with chlorates at 8 cents per pound is nearly 3 times as great, or $76.80 per acre. The acre chemical cost of carbon bisulfide at 75 cents per gallon amounts to $227.20.

Irrigation of the tilled areas did not facilitate or hinder the eradication of white top. This was due to the fact that carefully cultivated areas retained sufficient moisture to keep the weed plants growing vigorously.

SMOTHER CROPS

Numerous investigators have reported the successful use of smother crops in the eradication of perennial weeds. The use of such crops to complete the eradication of white top after 1 season's tillage would produce some returns from the otherwise fallow area the second year. The smother crops selected were corn, common millet, Early Amber sorghum, hemp, Manchu soybeans, and sunflowers. These crops were thickly drilled June 1, after the area had received 2 months cultivation the second season. This practice would save approximately 100 man and 300 horse hours from the second season's tillage requirements.

None of the smother crops seeded were effective in completing the eradication. In fact, all of the seeded areas required an additional season of cultivation after their removal to control the weed completely.

After the second tillage season rowed crops, checked both ways to facilitate thorough cultivation, should be used. Alfalfa or other hay crops should not be reseeded before the second year following the completion of eradication.

SUMMARY

Complete eradication of white top can be obtained by two applications of chlorates made at 10-day intervals during the blooming stage.

When the double treatment method was used the most effective combination proved to be a 1-pound initial application followed by a 4- or 5-pound dosage.

A later, third application did not increase the effectiveness of the chlorate.

Continued chlorate treatments seemed to develop a resistance to the chemical by the surviving plants.

Late fall, 6-pound, single sodium chlorate treatments gave 100% kills.

Two-ounce doses of carbon bisulfide applied to a depth of 6 to 8 inches at 18- to 20-inch intervals effected complete eradication.

Two seasons of thorough tillage followed by 2 years of check-rowed crops was the most economical and practical method for the eradication of large infestations.

Frequent irrigation did not improve or decrease the effectiveness of tillage operations.

Thickly seeded smother crops cannot be used to replace the second season's tillage operations.

LITERATURE CITED

1. ASLANDER, ALFRED. Experiments on the eradication of Canada thistle with chlorates and other herbicides. Jour. Agr. Res., 36 : 915–934. 1928.

2. BALL, W. S., MADSON, B. A., and ROBBINS, W. W. The control of weeds. Calif. Agr. Ext. Circ. 54. 1931.
3. BARNUM, C. C. The control of wild morning glory. Calif. Agr. Exp. Sta. Circ. 256, 1923.
4. LOOMIS, W. E., BISSEY, R., and SMITH, E. V. Chlorates as herbicides. Science, 74 : 485. 1931.
5. MEGEE, C. R. Some factors to consider in the use of chlorates for the control of weeds. Amer. Jour. Bot., 6: 1932.
6. ROGERS, C. F., and HATFIELD, Ira. Carbon bisulphide for the eradication of perennial weeds. Colo. Agr. Exp. Sta. Bul. 347. 1929.
7. SAMPSON, A. W., and PARKER, K. W. St. Johnswort on range lands in California. Calif. Agr. Exp. Sta. Bul. 503. 1930.
8. WILLARD, C. J. Additional suggestions on spraying weeds with chlorates. Ohio Bimonthly Bul. 142 : 8–11. 1930.
9. WOODMAN, R. B., and JONES, W. A. The eradication of weeds by chemicals. Chem. News, 144. 1932.

THE COMPARATIVE COST AND EFFECTIVENESS OF TILLAGE AND OF CHLORATES IN THE CONTROL OF MORNING GLORY, CANADA THISTLE, AND PERENNIAL SOW THISTLE[1]

D. C. TINGEY[2]

It has been estimated (4)[3] that losses from weeds in the United States amount to 12 times the loss from animal diseases, 1⅔ times the loss from plant diseases, and 3 times the loss from insect pests of plants. In monetary value, the annual loss from weeds is estimated at 3 billion dollars.

To eradicate completely even a single species from any section after it has once become well established is almost impossible. Ways and means must be devised to learn how to live with weeds. No one method of approach will accomplish this; all available resources must be adopted and put into practice; and, if possible, new methods must be devised in order to control these pests with a minimum of effort and expense.

From data secured in studies made in Utah since 1929 on the possibilities of using chlorates in the eradication of weeds, it was early recognized that this method of control was expensive. From 1929 to 1933 approximately 27 carloads of chlorates were used in Utah. Reports from Idaho (6) indicate that farmers in that section used nearly 2½ million pounds of chlorates from 1927 to 1930. Roughly, this method of control has averaged $50 or more to the acre. Even at such expense, in many cases, weeds on treated areas have not been eliminated. There is also the residual chemical effects which reduce the crop yields on these treated areas for one or more years which must be taken into consideration. In spite of all this, chlorates have their place in any weed-control program. Information on comparative efficiency of different tillage methods and chlorates in weed control is needed by farmers to guide them in the adoption of the most economical methods of control. The data reported here represent the results of studies made to determine the most efficient and economical methods of weed control.

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[2] Assistant Agronomist. The writer expresses his appreciation to all those who have made these studies possible, particularly to P. V. Cardon, Station Director, and to Harden Bennion, former State Commissioner of Agriculture, through whose efforts funds were made available for these studies, and to Dr. R. J. Evans, Agronomist, and to A. F. Bracken, Assistant Agronomist, for their helpful criticism concerning the manuscript. Much credit is also due to Dean F. McAlister and A. H. Blanchard, graduate students, who at different times had charge of the field work. Appreciation is also expressed to Professor C. T. Hirst of Logan and Mr. H. Holts of Nibley, both of whom supplied the land on which these experiments were conducted.

[3] Figures in parenthesis refer to "Literature Cited," p. 875.

METHODS

Studies of comparative cost and of the effectiveness of tillage and chlorates are reported for morning glory, Canada thistle, and perennial sow thistle. The morning glory and Canada thistle areas were located in the same field and were adjacent to each other. Both species were growing in competition with each other on a few of the plats. In each case the soil was capable of high crop production; however, it had become uniformly and heavily infested with weeds, consequently, there was little or no attempt to grow crops. Ordinarily, such crops as alfalfa, grains, sugar beets, and potatoes are produced on these lands with little or no irrigation, the water table being within 4 feet of the surface.

Both fields provided an opportunity for comparing the results of tillage on an experimental basis with that done by farmers on a somewhat larger scale. Approximately 15 acres in the field of morning glory and Canada thistle were infested, morning glory greatly predominating. In the perennial sow thistle field, approximately 2 acres were infested. Experimental plats were laid out on each area. The remaining infested area was tilled by the farmer, and the results he obtained were similar to those with similar methods obtained on the experimental plats.

The experimental plats were 1/30 acre in size, each treatment being replicated 3 times. The chemical treatments were duplicated on sub-plats of 1/240 acre and each of these was replicated three times. This would make essentially three replications of the chemical treatments on 1/120-acre plats.

In the tillage treatments, an ordinary moldboard plow was used together with a beet cultivator, equipped with 12 12-inch duck foot sweeps. Once over the area with the cultivator was sufficient to cut all growth. The experiments were started in the early spring of 1931 and were continued throughout 1932, with observations on all areas again in 1933. In arriving at the comparative costs of the various methods of control, it was assumed that each plowing would cost $3 an acre, each cultivation 50 cents an acre, and chlorates 10 cents a pound, including the cost of application. No doubt, these relative prices will change and vary for different sections, nevertheless they provide a basis for comparison. Whenever the standard error was used, it was obtained by Fisher's (5) variance method.

EXPERIMENTAL RESULTS

MORNING GLORY (*Convolvus arvensis*)

A rather complete tabulation giving the necessary treatments and results secured for the separate species is shown in Tables 1, 3, and 5. Table 1 shows the data for morning glory. The results are for 1931 and 1932 and observational data for 1933; however, costs are for 1931 only. This was because no additional chemical was applied until the fall of 1932. All but one of the tillage treatments for 1931 resulted in practically complete eradication. These results show some interesting comparisons, both from the standpoint of cost and of effectiveness. The tillage treatments receiving early spring plowing followed by either cultivation or plowing gave almost 100% kills, with costs ranging from $7.50 to $22 an acre. Few morning glory plants reappeared on these plats the following spring (Table 1). Contrasted with this was the failure to secure any kill, so far as could be determined, on areas where tillage was delayed until bloom, yet the cost amounted to $9.50 an acre. Shallow cultivation every other week was just as effective as weekly, with a reduction in cost from $12 to $7.50 an acre. Results from plowing every other week, on the other hand, were similar to those from shallow cultivation, but it cost $27 an acre.

It is interesting to contrast the results of tillage with those for chlorates and sodium arsenite, the latter being of no value other than to kill the top growth since the plant soon recovered. Except where tillage was delayed until bloom, the chlorates were not as effective in eradication and yet the costs were considerably more. To eradicate the remaining growth completely would probably have required another pound of chemical, since it is proportionately more difficult to eradicate the last few plants than it is the first 80 or 90%. Assuming another pound of chlorate would kill the remaining growth, the cost would then be nearly $50 an acre.

Results of frequent cultivation for the one season, as reported, were more effective under the conditions on the small-flowered morning glory than were those obtained by Stewart and Pittman (14) with the large-flowered species (*C. sepium*). While they reported satisfactory eradication by this method, yet some growth reappeared the following season, as evidenced by root and top growth obtained from sampling the plats. They found deep tillage to be no more effective than shallow and emphasized the importance of cultivating often enough to prevent any surface growth. Kezer (9) at Colorado concluded that proper cultivation for 2 years was necessary to eradicate morning glory. He emphasized the importance of preventing surface growth. Bioletti (2) in California found that by cutting the tops back every 5 days the weight of the roots were reduced by 70%, with a consequent scant top growth the next season. The cost of labor for the season was estimated at $9 an acre.

Latshaw and Zahnley (10) at the Kansas Station compared fallow, which consisted of cultivation, with sodium chlorate along with some other chemicals. The studies began in August 1925 and were continued the following season. The experiment consisted of single plats of sodium chlorate at two different concentrations, along with other

TABLE 1.—*Comparative costs and effectiveness of various tillage and chemical treatments in the eradication of morning glory* (*C. arvensis*).

Treatment		Date first plowed or chemical applied*	Stage of growth when first treated	Number tillage treatments or amount chemical applied (lbs. per acre)	Cost per acre†	Percentage kill, May 9, 1932
No.	Kind					
		1931				
1	Weekly cultivation...	May 5	1 in. high	19	$12.00	100‡
2	Alternate weekly cultivation..........	May 5	1 in. high	10	7.50	100‡
3	Alternate weekly plow	May 5	1 in. high	9	27.00	100‡
4	Same as 1, cropped 1932............	May 5	1 in. high	19	12.00	100‡
5	Delayed plowing, weekly cultivation.	July 17	Bloom	14	9.50	0
6	Atlacide...........	July 3	Early bloom	320	32.00	80
7	Altacide (2 applications, equal amts.).	July 3, Sept. 24	Early bloom	320	32.00	97
8	Sodium arsenite......	July 3	Early bloom	80 gal.	32.00	0
9	Check, no treatment.	......	......	...	....	0

1932

Treatment		Plowed	No. tillage treatments or Atlacide applied	Percentage kill, Oct. 26	Amount of Morning Glory, Aug. 1, 1933
No	Kind				
1	Cultivation..........	May 5	4	100	None
2	Cultivation..........	May 5	5	100	None
3	Cropped, corn and potatoes (weeds cultivated and hoed out)	May 5	5	100	None
4	Cropped, corn and potatoes (weeds cultivated and hoed out)	May 5	6	100	None
5	Cultivation..........	May 5	10	98	None
6	Atlacide.............		Dusted§	80	Trace
7	Atlacide.............		Dusted§	96	Trace
8	Atlacide.............		Dusted§	0	Light
9	Atlacide.............		Dusted§	0	Light

*Tillage ceased after October 21, 1931.

†Cost to the acre: Plowing, $3; cultivating, 50 cents; chlorates, 10 cents a pound.

‡Trace of morning glory returning on these plats.

§The weed growth on the chemically treated plats and checks was thoroughly dusted with Atlacide late in the fall after October 26, 1932. Shortly after the chemical was applied, the entire experimental area, including the tillage plats, was plowed and wheat was sown on the areas in 1933.

chemicals and duplicate plats of fallow. The plats were approximately 1/100 acre in area. On April 30, 1927, the results were compared. Two applications of sodium chlorate were made in the fall of 1925. The fallow treatments for the entire period consisted of 16 cultivations.

Sodium chlorate resulted in complete eradication, whereas the fallow resulted in no appreciable thinning of weed growth up to April 30, 1927. From this, the writers concluded that sodium chlorate was superior to fallow in the control of bindweed. However, when the cost of the two methods of control are considered, it presents a different situation. The sodium chlorate was applied at the rates of 250 and 500 pounds to the acre.

In a later publication (11), they state that sodium chlorate would cost about 8.5 cents per pound. With amounts applied, this represents an expenditure for chemical alone of $21.25 per acre in one case and of $42.50 in the other. On the other hand, fallow which consisted of 16 cultivations would cost approximately $10.50 an acre, assuming one plowing at $3 an acre and 15 cultivations at 50 cents each. For lighter applications,[4] the cost for sodium chlorate alone was $21.40 an acre as compared with $10.50 for fallow. Even though sodium chlorate gave a complete kill and tillage failed to do so after fall and summer treatments, it should be remembered that fallow has cost only about 50% as much as has sodium chlorate. One naturally wonders what the comparative cost would have been if the experiment had been continued until the weeds were eradicated on the fallow areas.

Call and Getty (3) in an earlier publication from the same station state that at the Fort Hays Station (Kansas), during 1 year, from 15 to 27 tillage operations, with an average of about 20 were required, resulting in one season in from 85 to 95% eradication. Latshaw and Zahnley (10), however, made only 16 cultivations from August 18, 1925, to October 19, 1926. Four of these were made in the fall and 12 during the following summer. The interval between cultivations varied from 9 to 31 days. In the spring of 1926, the first cultivation was made on April 30; the second on May 11; and the third on June 2. This latter interval was 22 days. At this season of the year, in order to be effective, cultivations need to be more frequent. If Latshaw and Zahnley (11) are justified in concluding that sodium chlorate is the most effective and economical means of killing bindweed known at the present time in Kansas, it certainly is not true for Utah, except on small areas or areas not accessible to cultivation. Even though Atlacide was used in these studies instead of sodium chlorate, the difference in effectiveness of the two chemicals on morning glory, as obtained in numerous other studies made in Utah, would not make up the difference in cost as compared with tillage.

Crop yields.—During the season following the treatments, the plants which were given early plowing followed by alternately weekly plowing and by frequent cultivation were cropped with early corn and potatoes. The acre yield of marketable potatoes was 411.3 and 395.3 bushels, respectively. The corn yields for both the morning glory and Canada thistle areas are shown in Table 2. It was only necessary to cultivate and hoe four or five times during the season. This is less than the average number of cultivations ordinarily made to control annual weeds. From Table 2 it is evident that higher corn yields were obtained on those areas receiving shallow and frequent cultivation as compared with the alternate weekly plowing. These differences, however, were not statistically significant. Since the advantage is for the shallow frequent cultivation and the fact that plowing is no more effective in eradication—though it costs about twice as much—the importance of adopting shallow cultivation rather than plowing as the method of control is obvious.

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[4] This cost for sodium chlorate is probably the minimum one could expect from this material at prices quoted, as the following year the same workers failed to obtain complete kills when as much as 375 pounds, or $31.87 worth of material, was applied to the acre. This latter amount is less than that which is generally recommended at other stations (6, 13).

TABLE 2.—*Average acre yield of roasting-ear corn, 1932, on morning glory and Canada thistle areas following two different tillage methods of eradication made in 1931, average of three replications.**

No.	Treatment (1931)	Yields (1932)		
		Roasting ears, doz.	Green weight, lbs.	
			Acre yield	Average weight per ear
	Morning-Glory Area			
4....	Shallow, weekly cultivation..............	1,895.0	9,090.0	0.3997
3....	Alternate weekly plowing.................	1,631.5	7,362.0	0.3760
	Canada-Thistle Area			
4....	Shallow, weekly cultivation..............	1,978.5	9,702.0	0.4087
3....	Alternate weekly plowing.................	1,246.5	5,742.0	0.3838

*For treatments in 1931 and 1932, see Tables 1 and 3.

In the fall before harvesting the crop, data were taken of weeds remaining on the plats, the results being shown in the last column in Table 1. It is evident that favorable kills had resulted from the treatments where tillage began early in the spring of 1931. On the plats where tillage was delayed until bloom, considerable growth reoccurred up until fall. In 1933, the entire experimental area was seeded to wheat. After the grain was cut, it was impossible to find any morning glory plants on any of the tillage plats. Even though the remaining growth on the chemical plats was dusted with Atlacide in the fall of 1932, there was a trace of growth returning in 1933.

CANADA THISTLE (*Circuum arvense*)

The treatments made and results secured for Canada thistle were similar to those obtained for morning glory. As shown in Table 3, however, a few more chlorate treatments were made. For the first year's treatment, the importance of starting tillage early in the spring as soon as growth begins is again obvious. Table 3 also shows that shallow cultivation every other week was practically as effective as weekly cultivation, though the costs are considerably less. Plowing every other week was about as effective as shallow cultivation, though the cost was considerably more.

Chemical treatments were not as effective on Canada thistle as were tillage treatments, except where tillage was delayed until bloom. The cost of chemical was considerably more. Sodium arsenite again failed to cause any appreciable amount of permanent injury. In the light of the standard error, the chlorate treatments show some differences in effectiveness. The applications made in July at the early bud stage were more effective than those made in September after bloom. This was especially true with the 320-pound application.

The rate of application used here with Atlacide ranged between those amounts usually recommended at other stations for sodium chlorate (1, 12, 15, 16). Stone and Delwiche (15) at Wisconsin report that the per acre cost of controlling Canada thistle with chlorates ranged between $20 and $75.

Potato yields following tillage and chlorates.—On the Canada thistle area, potatoes of the Bliss variety were planted on both tilled and chemically treated plats. Any returning weed growth was checked by cultivating and by hoeing. Average yields in bushels to the acre in each case from three replicated plats are shown in Table 4. Throughout the growing season the potato vines were yellowish on the chemically treated plats. While the yields were lower on these plats as compared with the tillage plats, they were not statistically significant.

TABLE 3.—*Comparative costs and effectiveness of various tillage and chemical treatments in the eradication of Canada thistle* (*C. arvense*).*

No.	Treatment	Date first plowed or dates chemical applied†	Stage of growth when first treated	No. tillage treatments or amount chemical applied, lbs. per acre	Cost per acre‡	Percentage kill, May 9, 1932
		1931				
1	Weekly cultivation...	May 5	1 in. high	19	$12.00	100§
2	Alternate weekly cultivation............	May 5	1 in. high	10	7.50	100§
3	Alternate weekly plowing...........	May 5	1 in. high	9	27.00	100§
4	Same as No. 1, cropped 1932..........	May 5	1 in. high	19	12.00	100§
5	Delayed plow, weekly cultivation........	Aug. 10	Bloom	7	6.00	0
6	Atlacide............	July 3	Early bud	320	32.00	84‖
7	Atlacide............	Sept. 5	Seed	320	32.00	63‖
8	Atlacide (3 applications, equal amounts).........	July 3, Aug. 24, Sept. 17	Early bud	480	48.00	92‖
9	Atlacide............	July 3	Early bud	640	64.00	95‖
10	Atlacide............	Sept. 5	Seed	640	64.00	89‖
11	Sodium arsenite......	July 3	Early bud	80 gal.	32.00	33‖
12	Check, no treatment.	......	......	...	....	0

*Some plats also infested with morning glory (*C. arvensis*).

†See footnote 1, Table 1.

‡See footnote 2, Table 1.

§Trace of Canada thistle returning on these plats.

‖Standard error of a mean chemical treatment, 2.2.

TABLE 3.—*Concluded.*

No.	Treatment	Plowed	No. tillage treatments or Atlacide applied	Percentage kill Oct. 26, 1932	Amount of Canada thistle, Aug. 1, 1933
			1932		
1	Cultivation	May 10	4 (lbs. per acre)	100	None
2	Cultivation	May 10	6	100	None
3	Cropped, corn and potatoes (weeds cultivated and hoed out)	May 10	3[**]	100	None
4	Cropped, corn and potatoes (weeds cultivated and hoed out)	May 10	3[**]	100	None
5	Cultivation	May 10	10	100[††]	None
6	Cropped, potatoes (weeds cultivated and hoed out)	May 10	5[††]	99[‖‖]	None
7	Cropped, potatoes (weeds cultivated and hoed out)	......	..	95[‖‖]	Trace
8	Atlacide	......	Dusted	70[‖‖]	Trace
9	Cropped, potatoes (weeds cultivated and hoed out)	May 10	5[‡‡]	99[‖‖]	None
10	Cropped, potatoes (weeds cultivated and hoed out)	......	5	99[‖‖]	Trace
11	Atlacide	......	Dusted[§§]	0[‖‖]	Considerable
12	Atlacide	......	Dusted[§§]	0[‖‖]	Considerable

[**] Three additional hoeings to cut out the returning growth.

[††] An average of 70 morning glory plants to the plat.

[‡‡] Five additional hoeings to cut out the returning growth.

[§§] Growth remaining was thoroughly dusted with Atlacide in the late fall of 1932. A few days later the entire area was plowed. The following spring wheat was sown on most of the area, with beets on the remaining portion.

[‖‖] Growth dry, difficult to determine the percentage kill. Two out of the three replications were adjacent to a non-treated area. It was evident that some growth was creeping in from these non-treated areas.

TABLE 4.—*Average acre yields (bushels) of Early Bliss potatoes following various treatments for the eradication of Canada thistle.*[*]

No.	Treatment (1931)	Date chemical applied	Mean acre yield of marketable tubers, bus.[†]	Acre yield of culls, bus.	Percentage of marketable tubers
3	Alternate weekly plowing	....	309	14	96
4	Weekly cultivation	....	271	17	94
6	320 lbs. Atlacide per acre	July 3	240	19	92
7	320 lbs. Atlacide per acre	Sept. 5	255	20	93
9	640 lbs. Atlacide per acre	July 3	236	16	93
10	640 lbs. Atlacide per acre	Sept. 5	263	19	93

[*] See Table 3 for more detailed treatments during 1931 and 1932.

[†] No statistical difference in the mean acre yield of marketable tubers for any of the treatments.

PERENNIAL SOW THISTLE (*Sanchus arvensis*)

Tillage treatments on perennial sow thistle were similar to those on morning glory and Canada thistle. While there were a few additional treatments of sodium chlorate, no sodium arsenite treatments were made. The data for perennial sow thistle are shown in Table 5.

The results obtained were similar to those obtained on morning glory and Canada thistle, except that tillage was proportionately more effective and the chemical less effective. On all tillage plats, except where tillage was delayed until bloom, there was no further

TABLE 5.—*Comparative cost and effectiveness of various tillage and chemical treatments in eradication of perennial sow thistle (S. arvensis).**

No.	Treatment	Date first treated†	Stage of growth first treated†	No. tillage treatments or chemical applied (lbs. per acre)	Cost per acre, fall 1930 and season 1931‡	Percentage kill, May 30, 1932
		1931				
1	Weekly cultivation...	May 15	1 in. high	18	$13.00	100**
2	Alternate weekly cultivation..........	May 15	1 in. high	9	8.50	100**
3	Alternate weekly plowing..........	May 15	1 in. high	6	22.00	100**
4	Same as No. 1 (cropped, 1932).........	May 15	1 in. high	18	13.00	100**
5	Tillage delayed till bloom, weekly cultivation...........	Aug. 11	Bloom	7	7.50	0
6	Atlacide............	July 2, Aug. 14, Sept. 19	Early bud	480	48.00	76††
7	Atlacide............	July 2, Sept. 4	Early bud	640	64.00	87††
8	Atlacide............	July 2	Early bud	640	64.00	87††
9	Atlacide............	July 2§	Early bud	640	64.00	67††
10	Atlacide............	Sept. 4	2d growth‖	640	64.00	55††
11	Atlacide............	July 2	Early bud	1,280	128.00	91††
12	Sodium chlorate.....	July 2, Aug. 19, Sept. 17	Early bud	480	48.00	92††
13	Sodium chlorate.....	July 2, Sept. 4	Early bud	640	64.00	96††
14	Check, no treatment.	......	......	...	....	0

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*The farmer had fall plowed in 1930 and had made two cultivations in early spring of 1931.

†Tillage ceased on October 20, 1931.

‡See footnote 2, Table 1.

§Growth mowed before treating.

‖To prevent seeding, growth had been mowed July 31, 1931.

**After July 20, there was no further growth of perennial sow thistle on these plats. Tillage was continued because of some perennial ground cherry (*Physalis* spp.) Costs, however, were calculated on the basis of the entire season.

††Standard error of a mean chemical treatment, 4.73.

TABLE 5.—*Concluded.*

No.	Treatment	Plowed	No tillage treatments or chemical applied (lbs. per acre)	Data observed as to perennial sow thistle	
				Oct. 29, 1932	July 1, 1933
			1932		
1	Cultivation.........	May 25	3	None	None
2	Cultivation.........	May 25	2	None	None
3	Cropped corn and potatoes (weeds cultivated and hoed out)	May 25	2	None || ||	None
4	Cropped corn and potatoes (weeds cultivated and hoed out)		3	None	None
5	Cropped, potatoes (weeds cultivated and hoed out).....	May 25	6	None	None
6	Atlacide............	......	Dusted§§	Growth dry	Trace
7	Cropped, potatoes (weeds cultivated, and hoed out)......	May 25	3	Trace	None
8	Cropped, potatoes (weeds cultivated and hoed out)......	May 25	3	Trace	None
9	Atlacide............	May 25	Dusted§§	Growth dry	Trace
10	Atlacide............	......	Dusted§§	Growth dry	Trace
11	Atlacide............	......	Dusted§§	Trace	Trace
12	Cropped, potatoes (weeds cultivated and hoed out)......	May 25	3	Trace	None
13	Cropped, potatoes (weeds cultivated and hoed out).....	May 25	3	Trace	None
14	Atlacide............	......	Dusted§§	Growth dry	Considerable

§§The remaining plants were thoroughly dusted with Atlacide in the late fall, after October 26, 1932. Sometime later the entire experimental area was plowed and the following spring barley was sown on the area.

|| ||Considerable perennial ground cherry on one of the replicated plats.

weed growth after July 20, 1931. Tillage treatments, however, were continued until October 20 because of the growth of perennial ground cherry on some of the plats. The costs, however, were based on treatments for the entire season. The costs listed in Table 5 for the eradication of perennial sow thistle by tillage are nearly twice what they should be. It was apparent that perennial ground cherry was far more difficult to eradicate than was perennial sow thistle.

The results of the chlorate treatments were not so favorable. As much as 1,280 pounds of chemical to the acre failed to give complete eradication, nevertheless the acre costs amounted to $128. These results show the possible waste of chemical by the application of too large an amount at one time.

In light of the standard error, there are differences in the chlorate treatments. The standard error was 4.73%, but to be significant a difference should be at least three times this amount, or approximately 14%. Mowing the weed growth prior to the time of the application of the chemical appeared to reduce its efficiency. The chemical was not as effective when applied at the rate of 640 pounds to the acre in one application made in September on second growth as compared with the one made in July at the early bud stage. Likewise, the September application was not as effective as the same amount applied in two applications of 320 pounds each, one made in July and the other made in September. However, there was no difference in effectiveness in the 640-pound application made in July as compared with the same amount applied in two applications, one-half the amount applied in July and the other one-half in September. It was evident that sodium chlorate was somewhat more effective than Atlacide.

YIELD OF POTATOES THE SEASON FOLLOWING VARIOUS TILLAGE AND CHLORATE TREATMENTS

Some of the plats treated in 1931 were cropped in 1932. This included both tillage and chlorate plats. Early potatoes of the Bliss variety were grown. Treatments made in 1931 and potato yields secured in 1932 are shown in Table 6. There were three replications for each treatment and because of the great variability, yields for each replication are included. From previous observations made in Utah on residual effects of chlorates, it was apparent that the depressing effects on crop yields were more pronounced in some soils than in others. These residual effects have been evident in some soils for as many as three or four years. Frequently, these greatly contrasted differences are shown in areas separated by only a comparatively short distance. Because of the evident erratic variability, due apparently to chlorates in this case, no attempt was made to deter-

TABLE 6.—*Acre yields of potatoes in 1932 following various treatments made in 1931 to eradicate perennial sow thistle.**

No. 1931 treatment after early spring plowing	Date of measurement	Acre yield of marketable potatoes in 1932 replications, bu.				Averages	
		1	2	3	Ave.	Acre yield of culls, bus.	Percentage of marketable tubers
3.. Alternate weekly plowing		443	404	339	395	76	84
4.. Shallow weekly cultivation		281	420	401	367	34	92
7.. 640 lbs. Atlacide per acre	July 2, Sept. 4	250	300	590	380	48	89
8.. 640 lbs. Atlacide per acre	July 2	205	9	350	188	29	87
10.. 640 lbs. Atlacide per acre	Sept. 4	45	0	230	92	31	75
12.. 480 lbs. sodium chlorate per acre	July 2, Aug. 19 Sept. 17	105	30	380	172	27	86

*For more detailed treatments during 1931 and 1932, see Table 5.

mine the standard error. Such extreme variations, however, were not characteristic of the yield obtained on the Canada thistle areas. Latshaw and Zahnley (11) and Aslander (1) report that sodium chlorate has no injurious effects on the soil during the season following its application. Schafer, *et al.* (13), however, report injury to spring wheat following the applications of sodium chlorate the previous summer.

SUMMARY

Comparative cost and effectiveness of tillage and chlorates are reported for morning glory, Canada thistle, and perennial sow thistle.

Tillage, except for treatments delayed until bloom, was more effective and cost materially less than chlorates. Costs were based on each plowing at $3 an acre, each cultivation at 50 cents an acre, and chlorates at 10 cents a pound, including cost of application. At these rates, the more effective chlorate treatments cost from 4 to 8 times more than the better tillage treatments.

The importance of starting tillage early in the spring was plainly evident. Delaying the tillage until the weed growth was in bloom cost more and required two seasons for complete eradication. Weekly cultivation and alternately weekly cultivation gave about equally good results; the latter, however, cost only about half as much. Plowing every other week was no more effective than cultivation, and the costs were more than twice as much.

As compared with tillage, chlorates caused a marked reduction in yield of potatoes the following season in one field though not in the other.

Under conditions of the experiments, there was a pronounced differential effect of tillage and chlorates on the three weed species. Morning glory was the most difficult to eradicate by tillage, followed by Canada thistle and perennial sow thistle, whereas, with chlorates the order was reversed.

LITERATURE CITED

1. ASLANDER, ALFRED. Eradication of Canada thistle with chlorates and other herbicides. Jour. Agr. Res., 36 : 915–934. 1928.
2. BIOLETTI, F. T. The extermination of wild morning glory. Calif. Agr. Exp. Sta. Circ. 69 : 12. 1911.
3. CALL, L. E., and GETTY, R. E. The eradication of bindweed. Kan. Agr. Exp. Sta. Circ. 101 : 18. 1923.
4. CHERRY, W. L. A suggested program of weed research and control. Agr. Service Dept. Comm. U. S. Chamber of Commerce, Washington, D. C. 1930.
5. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh : Oliver and Boyd. Ed. 4. 1932.
6. HULBERT, H. W., BRISTOL, R. S., and BENJAMIN, L. V. Methods affecting the efficiency of chlorate weed killers. Idaho Agr. Exp. Sta. Bul. 189 : 12. 1931.
7. HOWITT, T. E. Cooperative experiments in weed eradication. Ann. Rpts. Ontario Agr. Col. and Exp. Farm, 18 and 19 . 1917. (Abs. in Exp. Sta. Rec., 36 : 339. .)
8. KENNEDY, P. B. Weed control investigations in California. Calif. Agr. Exp. Sta. Ann. Rpt., 1927 : 41–42. 1927.
9. KEZER, A. Bindweed control in Colorado. Colo. Agr. Exp. Sta. Ann. Rpt., 1927 : 12. 1927.

10. LATSHAW, W. L., and ZAHNLEY, J. W. Experiments with sodium chlorate and other chemicals as herbicides for field bindweed. Jour. Agr. Res., 35 : 757–767. 1927.
11. ————, ————. Killing field bindweed with sodium chlorate. Kan. Agr. Exp. Sta. Circ. 136 : 15. 1928.
12. PIEPER, J. J. A year's progress in solving farm problems in Illinois. Ill. Agr. Exp. Sta. Ann. Rpt., 1930 : 67–68. 1930.
13. SCHAFER, E. G., LEE, O. C., AND NELLER, J. R. Eradicating the bindweed with sodium chlorate. Wash. Agr. Exp. Sta. Bul. 235. 1929.
14. STEWART, G., and PITTMAN, D. W. Ridding the land of wild morning-glory. Utah Agr. Exp. Sta. Bul. 189. 1924.
15. STONE, A. L., and DELWICHE, E. J. Weed eradication with chemicals prove expensive. Wis. Agr. Exp. Sta. Bul. 420. 1931.
16. WILLARD, C. J. An easier way to kill quackgrass and Canada thistle. Ohio Agr. Exp. Sta. Bimonthly Bul 139 : 121–125. 1929.

EFFECT OF SEED INJURY UPON THE GERMINATION OF *PISUM SATIVUM*[1]

H. W. HULBERT AND GERALD M. WHITNEY[2]

Peas to be marketed for seeding purposes must be high in vitality. Numerous mechanical, weather, and insect injuries occur during the growing and processing of the crop. The drilling, threshing, cleaning, and processing of seed peas causes considerable mechanical injury to the seedcoats and cotyledons. Seedsmen object to seeds with broken seedcoats because of the possibility of lowered germination. Moreover, mechanically injured seeds in a lot of peas fail to possess a good marketable appearance.

Sun scald is the most serious type of weather injury found in seed peas in Idaho. Injured seeds are characterized by a wrinkled appearance, and a loose, discolored seedcoat, which chips off readily.

The pea weevil is the most important insect enemy of the pea in the Palouse area. This insect consumes a large portion of the endosperm in its development. Weevil-infested peas are probably of little value for seeding purposes.

EQUIPMENT, MATERIAL, AND METHODS

In 1933 tentative federal standards for dried peas were promulgated by the U. S. Dept. of Agriculture. The thresher injury data herewith presented were secured from the thresher-run pea samples graded at the federal laboratory located at Moscow.

The drill injury data were obtained by running the seed through a 7-foot force-feed Superior drill that is used on the University Farm in seeding pea variety trials. In each determination the drill feed regutor was set at the desired rate of seeding and the drive wheel rotated a sufficient number of times to seed a 1/40-acre plat. Two hundred gram samples, taken from the entire lot by a Boerner sampler, were used for the injury analyses.

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[2] Agronomist and Research Assistant, respectively.

Geneva germinators made of galvanized iron 24 by 30 inches and 4 inches deep, with wooden covers 4 inches deep, were used for the germination tests. Canton flannel troughs 2 inches deep with paper towel lining were used for the germinating medium. The Canton flannel cloths and paper toweling were sterilized under 15 pounds pressure for 30 minutes before each germination test. The germinators were sterilized with a 0.1% mercuric chloride solution. Each germination test herewith reported is the average of duplicate 50-seed trials.

Finely divided, washed river sand free from organic material was used for the soil tests. These tests were run in 8-inch pots sterilized under 15 pounds pressure for 1 hour previous to planting. All germination tests were run in a steam-heated, thermostatically controlled greenhouse at a temperature of 60° F.

EXPERIMENTAL RESULTS

ACCURACY OF GERMINATIONS TEST

The methods of conducting and reading germination tests developed at the Idaho Agricultural Experiment station show a close relationship to actual field stands. The accuracy of these methods is shown by the data in Table 1. These data are the averages of germinator, greenhouse soil, and field stand readings of 20 lots of Alaska peas.

TABLE 1.—*Accuracy comparison of different germinative methods.*

Germinative method	Plants produced		
	Strong	Weak	Dead
Germinator	93.6	4.3	2.1
Greenhouse soil	94.2	4.1	1.7
Field stand	94.5	1.1	4.4

These data show that germinator tests can be read accurately in terms of field stands under good agronomic conditions. The plants read as "strong" were capable of completing their development and producing seed. It is apparent from the data that some of "weak" seeds as shown by germinator tests were read as "dead" under actual field conditions. All of the germination tests reported in this paper were read in a similar manner and the results shown represent the agricultural value of the seed.

CLASSIFICATION OF MECHANICAL SEED INJURY

Mechanical seed injuries, regardless of the cause, were classified into reasonably representative groups according to the extent of injury to the hull and cotyledon. The terms "slight", "severe", and "cracked" are used in this paper to describe the various groups.

"Slight" injury includes peas which have only a tiny check or crack in the hull. Such injuries cannot be removed accurately or economically by either processing or hand picking. Therefore, such injuries, if present, must remain and be planted with the sound seed.

The "severe" injury group includes peas with the hulls cracked most of the way around or which have lost portions of their seedcoat. In this group are included those seeds in which the cotyledons are loosely held together. Processing often breaks apart the cotyledons of such seeds after which they are removed by the cleaning machinery.

"Cracked" peas consist of only one cotyledon or a portion of a cotyledon. Usually the embryo is entirely removed in the cracking process.

EXTENT OF THRESHER INJURY

Thresher-run peas under the tentative federal standards are graded on a dockage basis. Dockage in Alaska peas was determined by screening a 1,000-gram sample over a 12/64 by ¾ inch slotted screen. The dockage determination removed nearly all of the cracked peas. An analysis of the dockage from 500 lots of peas representing approximately 35 million pounds showed an average of 1.3% of split peas. This represents a loss in cracked peas of 455,000 pounds, and a monetary loss of $15,925 at $3.50 per hundred, the 1933 basic price.

Analyses were made of 200-gram samples taken from 350 lots of dockage-free Alaska peas to determine the percentage of cracked and broken-hulled seeds. The data secured from these analyses are shown in Table 2. The peas represented by the percentages shown were classified in the "severe" injury group.

TABLE 2.—*Percentage of seed injury in dockage-free Alaska peas.*

Percentage cracked and broken hulls	Number of samples in grade	Percentage of samples in grade	U. S. grade	Loss to grower in pounds
0.01–1.0.....	73	20.9	Extra No. 1	36,575
1.1– 3.0.....	193	55.2	Extra No. 1	386,400
3.1– 5.0.....	55	15.8	Extra No. 2	221,200
5.1–10.0.....	25	7.0	Extra No. 3	183,750
10.1–over....	4	1.1	Sample	38,500
Total......	350	100.0		866,425

Since the data shown in Table 2 are representative of the 35 million pounds of peas graded, an additional monetary loss of $30,324 is entailed at the previous basic price. Thus, the total loss from crackage was $46,249, or nearly $100 for each grower.

Crackage can be eliminated to a large extent if care is used in the harvesting operations. The removal of part or all of the concave teeth in the thresher cylinder and reduced cylinder speed will materially decrease the injury. Thresher or combine elevators and augers should be adjusted or redesigned to reduce seed injury to a minimum.

GERMINATION OF INJURED SEED

The injury group of peas classified as "cracked" failed to germinate. The effect of slight and severe injury upon germination is shown in Table 3. These data were secured from duplicate germination tests of Alaska peas.

TABLE 3.—*Effect of seed injury upon the germination of Alaska peas.*

Type of injury	Percentage germination		
	Strong	Weak	Dead
None	93.5	5.5	1.0
Slight	43.7	12.0	44.3
Severe	33.7	12.5	53.8
Average of injured	38.7	12.3	49.0

Nearly one-half of the injured peas failed to germinate, while only 39.7% produced strong plants. These data indicate the seriousness of seedcoat injury in seed peas. Even slight injuries reduce the germination to a considerable degree.

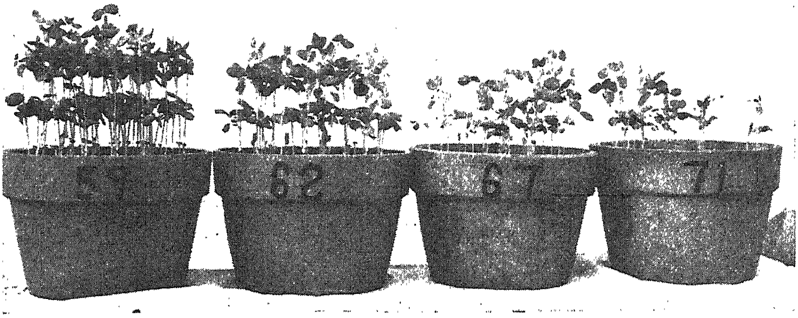

FIG. 1.—Effect of mechanical injury upon germination. No. 59, sound; No. 62, slightly injured; No. 67, distinctly cracked coat; No. 71, severely injured.

Additional information upon the effect of various types of seedcoat injury upon vitality is shown in Table 4. These data were secured from seed peas more carefully classified according to the type of injury. In addition to the usual untreated tests, duplicate plantings of seed treated with a 1 to 1,000 solution of mecuric chloride were made in sand. Fig. 1 illustrates the comparative vitality of injury-free, slightly injured, severely injured, and cracked peas.

Under greenhouse conditions, mercuric chloride used as a seed disinfectant did not improve the percentage of strong plants in injured seed lots. Probably few harmful fungi and bacteria were present under the controlled conditions of the experiment. Seed disinfectants may be of some value under field conditions, particularly if the climatic conditions present are favorable for the development of fungi.

Germination decreases in proportion to the severity of the injury. This fact is apparent to a marked degree as the seedcoat injury increases in extent. Seed with the coats partially removed, but with the cotyledons intact, are more likely to produce a higher percentage of strong plants than those with distinct cracks in the coat. This is due to

TABLE 4.—*Effect of seed injury upon the vitality of Alaska peas.*

Type of injury	Seed treatment	Percentage of germination		
		Strong	Weak	Dead
None	None	95	5	0
	$HgCl_2$	93	7	0
Slight coat injury	None	72	21	7
	$HgCl_2$	74	21	5
Distinctly cracked coat	None	49	36	15
	$HgCl_2$	54	37	9
Split coat and loose	None	48	44	8
	$HgCl_2$	32	30	38
Coat one-half to three-fourths gone	None	71	24	5
	$HgCl_2$	82	16	2
Coat entirely gone	None	55	30	15

the direct cause of the injury. A definite blow breaks the coat, loosens the cotyledons, and severs the young embryo from its point of attachment. Seed coats are partially or entirely removed by abrasion or grinding, thus leaving the cotyledons and embryos intact.

DRILL INJURY AND GERMINATION

Calibration studies made on pea varieties caused a considerable amount of seed injury. In order to determine the extent of this injury, two smooth- and two wrinkle-seeded pea varieties were carefully hand picked and run through the drill at various rates of seeding. The rates used ranged on either side of the normal rates for the variety. Table 5 shows the percentage of the various types of injury obtained at the different seeding rates.

Wrinkle-seeded peas showed considerably less injury than smooth-seeded ones. This is due, undoubtedly, to the harder texture of the wrinkled sorts.

Considerable variation occurs in the percentage of injury obtained from the different seeding rates. Nevertheless, there was no consistent increase in crackage as the rate of seeding was decreased. Moreover, in certain instances the injury was greatest at the higher drill sets. These variations are to be expected since the clogging and bridging of the seed in the drill feeds occurs in a haphazard manner.

The relationship of size and type of peas to drill injury and subsequent germination is shown in Table 6. The injury data in this table were summarized from Table 5. Separations made from seed run through the drill were used to obtain the germinative percentages.

Idabell, a large, smooth-seeded variety received twice as much injury as the small, smooth-seeded Alaska variety. Apparently the extent of seed injury in smooth-seeded types is closely related to seed size. In the wrinkled sorts, size of seed had little effect upon the amount of injury.

TABLE 5.—*Percentage of drill injury in different varieties of peas at various seeding rates.*

Variety	Rate of seeding, pks.	Type and percentage of injury			
		Slight	Severe	Cracked	Total
		Smooth-seeded			
Alaska............	9	2.26	2.18	0.38	4.82
	8	1.89	1.33	0.13	3.35
	7	1.51	3.56	0.64	5.71
	6	2.65	3.17	0.54	6.36
	5	2.50	2.40	0.25	5.15
Average.........	....	2.16	2.53	0.39	5.08
Idabell............	11	4.48	5.30	1.09	11.87
	10	4.10	4.60	1.06	9.76
	9	2.92	5.91	1.03	9.86
Average.........	....	3.83	5.27	1.06	10.16
		Wrinkle-seeded			
Earliest Perfection..	10	1.41	1.10	0.15	2.66
	9	0.42	0.43	0.14	0.99
	8	1.41	0.73	0.20	2.34
	7	1.26	....	0.12	1.38
Average.........	....	1.12	0.57	0.15	1.84
Allans Canner......	11	1.71	0.51	0.67	2.89
	10	1.18	....	0.48	1.66
	9	0.73	0.24	0.56	1.53
	8	0.97	0.24	0.44	1.65
Average.........	...	1.15	0.25	0.53	1.93

TABLE 6.—*Effect of size and type of peas upon drill injury and germination.*

Variety and treatment	Size and type of seed	Total injury, %	Germination, %		
			Strong	Weak	Dead
Idabell: Check.....	Large, smooth	None	80.0	12.3	7.7
Through drill......		10.16	72.0	15.0	13.0
Alaska: Check.....	Small, smooth	None	93.5	5.5	1.0
Through drill......		5.08	88.7	8.1	3.2
AllansCanner:Check	Mid-sized, wrinkled	None	84.7	7.0	8.3
Through drill......		1.86	72.6	11.4	16.0
Earliest Perfection: Check..........	Small, wrinkled	None	77.0	13.0	10.0
Through drill......		1.84	76.2	11.4	12.4

A further study of the data in Table 6 discloses a striking relationship between the total injury percentage and loss in vitality. Therefore, drill injury of smooth-seeded peas becomes an important factor in securing satisfactory field stands of strong plants.

ELIMINATION OF DRILL INJURY

Alaska peas were subjected to several different seed treatments in an attempt to reduce drill injury and eliminate possible molds and fungi. Table 7 presents the crackage and germination data secured from these trials.

TABLE 7.—*Effect of seed treatments upon drill injury and germination of Alaska peas.*

Treatment	Type and percentage of injur				Germination, %		
	Slight	Severe	Cracked	Total	Strong	Weak	Dead
Check, not drilled....	....	....	....	....	93.5	5.5	1.0
Check, drilled.......	0.29	0.42	0.11	0.82	90.0	6.0	4.0
Graphite, not drilled.	....	....	....	....	89.0	8.0	3.0
Graphite, drilled.....	....	0.20	....	0.20	91.0	9.0	0.0
Nitragin, drilled.....	1.65	3.90	0.31	5.86	96.0	2.0	2.0
Nitragin plus graphite, drilled........	....	0.91	0.14	1.05	93.0	4.0	3.0
University culture, drilled...........	1.97	3.05	0.26	5.28	86.0	86.0	8.0
University culture plus graphite, drilled...........	0.28	0.98	0.03	1.29	90.0	7.0	3.0
Ceresan, not drilled...	....	....	....	....	91.0	7.0	2.0
Ceresan, drilled......	5.22	15.87	1.98	23.07	79.0	11.0	10.0
Ceresan plus graphite, drilled........	....	0.19	....	0.19	91.0	7.0	2.0
Sterocide, not drilled..	....	....	....	....	96.0	2.0	2.0
Sterocide, drilled....	0.50	1.18	0.19	1.87	90.0	6.0	4.0
Sterocide plus graphite, drilled........	0.30	0.17	0.04	0.51	90.0	5.0	5.0
Copper carbonate, not drilled...........	....	....	....	....	80.0	15.0	5.0
Copper carbonate, drilled...........	3.33	12.79	2.81	18.93	73.0	11.0	16.0
Copper carbonate plus graphite, drilled...........	0.51	0.28	0.18	0.97	70.0	20.0	10.0

Graphite[3] was applied to seed peas by the same equipment used to treat seed wheat with copper carbonate. This inert product was uniformily distributed in a thin layer over the entire seedcoat of the peas. Graphited peas were slick and did not clog or bridge-up in the drill, thus drill injury was almost entirely eliminated. Moreover, graphite had no apparent effect upon germination. This fact is shown definitely by the comparative germination tests shown in Table 6. Soil tests made in sand and actual field trials made later confirmed this fact. Graphited peas fed through the drill at a more uniform rate. In addition, the drill delivered nearly 30% more graphite-treated than untreated seed at the same drill set. The use of this material, therefore, would necessitate the recalibration of the drill if the peas were to be seeded at the normal rate for the variety. Trials are now in progress to develop a fungicide with a graphite base that would be practical for general usage.

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[3] F. L. BURKART, Field Superintendent in Agronomy, suggested the use of graphite.

Two brands of culture were used both alone and in combination with graphite. Commercial Nitragin was purchased on the open market. The University culture was prepared by the Bacteriology Department of the Idaho Agricultural Experiment Station. The latter culture was grown on gelatin and applied to the seed in a water-sugar solution. Both cultures increased the amount of injury to approximately the same extent. The increased injury over that of untreated seed was due to the stickiness of the inoculated peas. A minimum amount of injury occurred when the inoculated peas were graphited.

Ceresan had no effect upon the germination of peas. However, when this product was used as a seed treatment, friction was increased greatly and consequently the percentage of seed injury was unusually high. Nevertheless, the addition of graphite counteracted the effect of the Ceresan and practically eliminated the crackage.

Sterocide caused the least injury of any of the seed disinfectants used in the experiment. When graphite was added, the injury, as in previous cases, was almost eliminated.

Copper carbonate not only caused a large amount of seedcoat injury, but also decreased the percentage of germination. Even with the seed injury almost entirely eliminated by the addition of graphite, the germination was not increased. It was observed in reading the germination tests that the roots from the copper carbonate treated peas were poorly developed or entirely absent. In most cases these roots had started growth but seemed to have been corroded or eaten away by the chemical. However, the stem sprouts appeared normal.

EFFECT OF SUN-SCALD UPON GERMINATION

Peas are grown in Idaho under both irrigated and non-irrigated conditions. In 1933 considerable sun-scald injury developed at Aberdeen under irrigation. Sun-scald occurs after the peas are well formed in the pods, but before they have completed their growth. In irrigated areas the injury is caused by improper irrigation during extremely hot weather. This injury develops in all sections during warm weather

TABLE 8.—*Effect of sun-scald on the vitality of wrinkle-seeded peas.*

Variety and seed condition	Percentage of germination		
	Strong	Weak	Dead
Allans Canner:			
Sound, mature	92	5	3
Sun-scalded	4	0	96
Everbearing:			
Sound, mature	94	4	2
Sun-scalded	3	0	97

under dry soil conditions. Table 8 shows the effect of this injury upon germination in comparison with mature seed of the same variety.

WEEVIL INJURY AND GERMINATION

Peas grown in the Palouse area are marketed on the basis of the tentative federal pea standards established in August, 1933. The peas graded under these standards in 1933 showed an average weevil injury of 3.2%. Since 35 million pounds were graded, the weevil dockage meant a loss of 1,120,000 pounds or an actual cash loss of $39,200. The sale value of weevily peas in 1933 was $10.00 per ton. Subtracting the feeding value from the total loss, leaves a net loss of $33,600 or approximately $65.00 for each grower.

Since cleaning and processing of seed peas will not remove all of the weevil-infested peas, it seemed advisable to procure definite information upon their germinative value. Table 9 shows the results of the germination tests.

It is evident from these data that weevily peas are of little value for seeding purposes. Therefore, weevily lots of peas to be used for seed should be carefully cleaned and processed.

TABLE 9.—*Effect of weevil injury upon the germination of Alaska seed peas.*

Seed condition	Percentage of germination		
	Strong	Weak	Dead
Weevil infested	6.5	0	93.5
Hand picked	92.0	0	8.0

SUMMARY

Properly read germination tests are an accurate index of the field value of seed peas. Considerable mechanical loss occurs in the harvesting, threshing, cleaning, and drilling of seed peas. Mechanical seed injury seriously reduces the value of peas for planting purposes. Germination decreases in proportion to the severity of the injury. Force-feed drills cause considerable mechanical injury to smooth-seeded pea varieties.

Graphite, applied as a thin, uniform coating to seed peas reduced drill injury to a minimum. Pea seed germination was not affected by graphite. Since graphite increased the rate of seeding at a given drill set, the drill must be recalibrated so that it will plant the proper amount of seed.

Sun-scalded and weevily peas are of little value for planting purposes.

CORRELATED INHERITANCE WITH SPECIAL REFERENCE TO DISEASE RESISTANCE IN SPRING WHEAT[1]

LAXMAN G. KULKARNI[2]

The plant breeder is interested primarily in the improvement of varieties of crop plants and for this purpose a knowledge of the manner of inheritance of different characters and their relations to each other is of vital importance.

The investigation described here was undertaken with a threefold purpose. First, to study with spring wheat the inheritance of field reaction to stem rust in a cross between a highly resistant and a highly susceptible variety. Second, to determine to what extent different types of rust reaction affect the shrivelling of the grain. Third, to learn the homozygosity of varieties as tested by their greenhouse reaction to physiologic forms 21 and 36.

REVIEW OF LITERATURE

INHERITANCE OF REACTION TO STEM RUST

The inheritance in wheat, under field conditions, of "mature plant" reaction to stem rust and of seedling resistance in the greenhouse has been studied by several investigators (7, 8, 9, 10, 13).[3] The existence of a large number of physiologic forms appeared less serious from the standpoint of plant breeding when Aamodt (1) showed that the inheritance of resistance in the seedling stage to 11 physiologic forms was governed by a single pair of genetic factors.

After the discovery of physiologic forms, it was Hayes, Stakman, and Aamodt (11) who first demonstrated that certain wheat varieties and hybrids, though susceptible in the seedling stage under greenhouse conditions to some physiologic forms, showed a moderate degree of rust resistance under field conditions to many and perhaps all physiologic forms.

From the results of studies of several investigators (2, 7, 8, 9), it has become quite clear that the reaction of wheat varieties and hybrids in the seedling stage to single forms of rust as determined by greenhouse tests is not necessarily a criterion of the reaction under field conditions to these same physiologic forms or to a collection of forms.

INHERITANCE OF LIGULE

Studies of inheritance of liguleless condition in Gramineae are reported by Emerson (3) in corn and by Nilsson-Ehle and Love and

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[1] Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Submitted in partial fulfillment of the requirements for the degree of doctor of philosophy at the University of Minnesota. Received for publication June 22, 1934.

[2] Graduate Assistant. The writer wishes to thank Dr. H. K. Hayes for his valuable advice regarding methods of conducting the study and in the interpretation of results. The rust forms were furnished by the Division of Plant Pathology and Botany and Dr. E. R. Ausemus kindly gave advice and aid in the production of the rust epiphytotic.

[3] Figures in parenthesis refer to "Literature Cited," p. 892.

Craig (12) in oats. In corn, two independently inherited recessive factors for liguleless have been determined either alone when homozygous for the recessive condition giving an absence of the ligule. In oats the liguleless condition was reported to be monogenic, digenic, and trigenic in different sorts. But the double and triple recessive condition of the liguleless character must be occurring in nature extremely rarely.

MATERIALS AND METHODS

F_3 lines of a cross between Hope and a variety of common wheat called Liguleless, which does not produce a ligule, were studied. Random F_2 plants were kindly furnished by Dr. Ausemus for this study. Hope is highly resistant to stem rust in the field and produces a ligule. The second parent is highly susceptible and is liguleless. Ninety-eight F_3 lines were studied for the inheritance of the ligule and satisfactory notes on rust reaction of 50 lines selected at random were obtained in 1933. F_3 lines were placed in four classes, *viz.*, homozygous for resistance, segregating with a predominance of resistant plants, segregating with a predominance of susceptible plants, and homozygous for susceptibility.

The second phase consisted of a study of 140 random F_3 lines of a cross between Ceres x Hope (III–31–2), a resistant variety, and Ceres x Double Cross (III–31–12), a semi-resistant variety. Lines segregated for resistance and semi-resistance, but no susceptible lines were obtained. On the basis of percentage of rust, three further subclasses were made in each of the resistant and semi-resistant groups. Thus the semi-resistant group with general infection over the culm consisted of class 4 with more than 60% rust, class 5 with more than 20% but less than 60% rust, and class 6 with less than 20% rust. The resistant group with rust infection restricted to the nodal region consisted of class 7 with heavy local infection, class 8 with less pustules than class 7, and class 9 free from rust.

Notes on plumpness of seed were taken on an individual plant basis and eight groups representing class centers for different grades of plumpness were made. Yield of individual plants was taken in grams.

Just before heading an epiphytotic of rust was produced artificially by inoculating susceptible plants in border rows with water solution of rust suspensions and also by spraying such solution on the F_3 lines. Twenty-three physiologic forms of rust were used in the production of the field epidemic.

EXPERIMENTAL RESULTS

THE HOPE-LIGULELESS CROSS

Inheritance of ligule.—The results are explained on the basis of two dominant duplicate factors, either one alone in the homozygous or heterozygous condition producing the ligule. On this basis the constitution of Hope was $Lg_1 Lg_1 Lg_2 Lg_2$ and of the liguleless parent, $lg_1 lg_1 lg_2 lg_2$. The F_1 was liguled. Of the 98 F_2 plants studied, 90 were liguled and 8 liguleless, which gives a P value of .30 to .50 for a 15:1

ratio, showing a good fit. The F_3 lines gave 38 liguled, 23 lines giving a 15:1 ratio for liguled and liguleless, 25 lines giving a 3:1 ratio and 8 liguleless lines. These figures were compared with the 7:4:4:1 ratio, which is to be expected on the basis of the above hypothesis, and this gave a P value of .50 to .70, showing a good fit. The goodness of fit was studied further by determining the number of families in each class that fell within the limits of 1, 2, 3, and 4 times the probable error. The results again gave a very good fit. These statistical considerations prove that the ligule character is determined by two pairs of duplicate factors.

Rust reaction.—The F_1 was classified as semi-resistant. In F_2, of the 453 plants studied, 93 were resistant, 99 semi-resistant, and 261 susceptible, thus showing a predominance of susceptibility. Placing the semi-resistant class and susceptible together there was a ratio of 93 resistant to 360 non-resistant and this gives a P value of .30 to .50 for a 13:3 ratio. The results are explained on the basis of a dominant R factor for resistance carried by Hope and an inhibitory factor I in the presence of R giving susceptibility. The II factor pair is carried by the liguleless parent. Of the 50 F_3 lines studied, 3 were semi-resistant, 2 resistant, 4 had a predominance of resistant plants, 20 a predominance of susceptible plants, and 21 were susceptible. The occurrence of semi-resistant lines in F_3 could only be explained by factors other than those responsible for the resistant type of infection. Leaving these lines out of consideration and comparing the remaining figures with the expected 7:6:2:1 ratio, which is to be expected on the above hypothesis, a P value of .70 to .80 was obtained. This supports very well the above-postulated hypothesis.

On the basis of X^2 for independence, in this case 7.50 with a P value of .10, it was concluded that the factors determining rust reaction and factors conditioning the presence or absence of the ligule were not closely associated in inheritance.

TYPES OF RUST REACTION AND THEIR EFFECT ON PLUMPNESS AND YIELD

Reaction to stem rust in the field.—Of the 140 F_3 lines studied, 45 bred true for resistance; 66 segregated for resistance and semi-resistance, and 29 bred true for semi-resistance. No lines with a susceptible type of reaction were obtained. These results are explained on the basis of a two-factor hypothesis. A is a dominant factor for resistance carried by Hope and hence present in the Ceres x Hope parent. B is a semi-resistant factor carried by Ceres. Hence the parental genotypes will be Ceres x Hope = AABB and Ceres x Double Cross = aaBB. Since the factor pair for semi-resistance is in a homozygous condition, the segregation is only for one factor pair. On this basis the F_3 results gave a P value of .10 to .20. Goodness of fit for each individual segregating line was calculated and the number of families that fell within 1, 2, 3, and 4 times the P. E. were determined. This gave a very good agreement to mathematical expectation. These considerations indicate that the Hope type of resistance is carried by the Ceres x Hope parent and is determined by a single factor pair, and that the factor pair for semi-resistance is carried by Ceres and hence is present in both parents. This conclusion is based on crosses between Ceres and Double Cross made at University Farm, St. Paul, Minnesota, where some completely susceptible types were obtained in F_2 and F_3.

Effect of different rust classes on shrivelling of seed.—Notes on plumpness of seed were taken for each individual plant. All the results are interpreted on the basis of an analysis of variance. For this purpose the average plumpness for each class of rust in each family was determined. Thus, the effects of different classes of rust on plumpness and yield were studied. The parental rows offered good material for studying this relation. In case of the Ceres x Hope parent, only those rows which contained plants in all three rust classes 7, 8, and 9 and in the case of Ceres x D.C. only those rows which contained plants in rust classes 4 and 5 are considered. The final results is given in Table 1.

TABLE 1.—*Final results of analysis of variance for studying the effect of different types of rust reactions on the plumpness of seed in parental rows of Ceres x Hope and Ceres x D. C.*

Rows of	Mean square for		Value of F	Value of F for	
	Rust classes	Error		5%	1%
Ceres x Hope..........	1.1400	.2784	4.0984	3.55	6.01
Ceres x D. C..........	.0073	.1632			

The value of F is obtained by dividing the mean square for rust classes by the mean square for error (15).

Since the variation due to rust classes in the Ceres x Hope rows exceeds the 5% point but not the 1% point, it may indicate that there is reason for the belief that rust classes 7, 8, and 9 do differ significantly in their effect on seed plumpness. In rows of Ceres x D.C., since the mean square for error is greater than the mean square for rust classes, it is evident that the variation is due to chance alone.

A further indication of how the rust classes in the Ceres x Hope parent differ from one another in plumpness of seed is obtained by comparing the various means and obtaining the S.E. of the difference between two means, which is $\sqrt{\frac{.2784 \times 2}{10}}$ or .0557. The average plumpness of seed of plants falling in class 7 was 3.4100; in class 8, 3.0000; and in class 9, 2.7400. So the difference between the plumpness of classes 7 and 8 was .4100 ± .0557; between classes 7 and 9, .6700 ± .0557; and between classes 8 and 9, .2600 ± .0557. All the classes differ quite significantly from each other since the differences are more than twice their S. E.

The hybrid lines were divided into four main groups, namely, lines homozygous for the resistant type of reaction, *viz.*, 7, 8, and 9 groups; lines homozygous for the semi-resistant type, *viz.*, 4 and 5 groups; lines segregating for rust reaction classes 4, 7, and 8; and lines segregating for classes 5, 7, and 8. The study of the effect of different types and classes of rust on plumpness of seed is given in Table 2.

TABLE 2.—*Final results of analysis of variance for studying the effect of different types of rust reactions on the plumpness of seed in F_3 lines.*

Types of F_3 lines	Mean square for		Value of F	Value of F for	
	Rust classes	Error		5%	1%
Homozygous resistant (7, 8, 9)............	1.1388	.1970	5.7807	3.32	5.39
Homozygous semi-resistant (4, 5).........	.0422	.1041	....	....	....
Segregating for rust groups (4, 7, 8).......	6.0132	.3782	15.8995	3.23	5.18
Segregating for rust groups (5, 7, 8).......	.8303	.9302	....	....	....

Thus, the value of F for lines homozygous for the resistant type of reaction and lines segregating for rust groups 4, 7, and 8 exceeds the 1% point. Hence, groups 7, 8, and 9 differ significantly from one another in their effect on seed plumpness and also the effect of rust groups 4, 7, and 8 differ significantly from one another in their effect on seed plumpness.

The difference in the effects due to various rust classes in lines homozygous for the resistant type of reaction was further studied by obtaining the S.E. of the difference between two classes which is $\frac{.4438}{\sqrt{16}} \times \sqrt{2}$ or .1568, while the average plumpness for plants of class 7 was 3.0000; of class 8, 2.6563; and of class 9, 2.4750. So the difference between class 7 and class 8 was .3437 ± .1568; between classes 7 and 9, .5250 ± .1568; and between classes 8 and 9, .1813 ± .1568.

From these results it is evident that the difference in effect of rust classes 7 and 8 on seed plumpness in the first case and between 7 and 9 in the second case is statistically significant. In other words, class 7 causes more shrivelling of seed than class 8 or class 9. But the difference between the effects of class 8 and class 9 is not statistically significant, i.e., class 8 does not differ from class 9 in its effect on the plumpness of seed.

In case of lines segregating for rust groups 4, 7, and 8, the S.E. for the difference between the groups is $\frac{.6150}{\sqrt{20}} \times \sqrt{2}$ or .1944, while the average plumpness of seed of plants of rust class 4 is 4.0250; of rust class 7, 3.1500; and of rust class 8, 3.0150. Thus, the difference between classes 4 and 7 was .8750 ± .1944 and between classes 4 and 8, 1.0100 ± .1944. Hence, class 4 differs significantly from class 7 and class 8 in its effect on seed plumpness.

In order to get an indication as to whether the average effect of rust classes 4 and 5 on seed plumpness differs from the average effect of rust classes 7, 8, and 9, a comparison was made between the semi-resistant and resistant groups. Fisher's (4) formula for t was used. $t = \frac{\overline{X}_1 - \overline{X}_2}{S} \sqrt{\frac{n_1 n_2}{n_1 + n_2}} = \frac{.6821}{.1595} \text{ x } 2.8948 = 12.3796$. Looking up the value for t under degrees of freedom for 30, since 34 degrees of freedom in the experiment are much closer to 30 than to infinity, we have for the 1% point a value of t = 2.750 and since the obtained value of t, which is 12.3796, exceeds the 1% point, the difference is quite significant, meaning that classes 4 and 5 of the semi-resistant group cause more shrivelling of the seed than classes 7, 8, and 9 of the resistant group.

Relation of plant yield with reaction to different types of rust.—The data were assembled and calculated in the same way as in the case of seed plumpness. The final results are shown in Table 3.

TABLE 3.—*Final results of analysis of variance for studying the effect of different types of rust reactions on the yield of plants in F_3 lines.*

Types of F_3 lines	Mean square for		Value of F	Value of F for	
	Rust classes	Error		5%	1%
Homozygous resistant...	.3111	.6528	....	....	....
Homozygous semi-resistant..............	1.0560	.3869	2.7293	4.38	8.18
Segregating for rust groups 4, 7 and 8.....	.0215	.8045	....	....	....
Segregating for rust groups 5, 7 and 8.....	1.6201	.6172	2.63	3.40	5.61

It is clear from this table that no significant variation in yield of individual plants can be attributed to differences in rust infection as exhibited by the different rust classes studied. As there was an effect of different types of rust on seed plumpness and as seed plumpness is necessarily correlated with yield, it is apparent that other factors of major importance that condition yield were of so great effect that it was impossible in these F_3 lines to demonstrate the effect of rust on yield.

The third phase of the study consisted of testing the homozygosity of pedigreed lines of winter and spring wheat, where H 44 and Hope were used as one parent and where individual plant study was carried on for at least five generations. The material used in this study consisted of lines that appeared homozygous and that had been placed in rod row trials in the cooperative studies conducted by the Minnesota Station and the U. S. Dept. of Agriculture. The study was made on the basis of their reaction as tested in the seedling stage to physiologic forms 21 and 36 furnished by the Department of Plant Pathology. The types of seedling reactions used were similar to those described by Stakman and Levine (16) who explain 0 as immune, 1 and 2 as very resistant, 3 as moderately susceptible, 4 as very susceptible, and x as indeterminate. Table 4 gives the reaction of lines to physiologic forms 21 and 36.

TABLE 4.—*Classification of lines on the basis of types of seedling reaction to forms 21 and 36.*

Class	Type of reaction	Number of lines	
		Form 21	Form 36
I........	Breeding true to 0 fleck or the 1 or 2 types of reaction	43	60
II.......	Mostly 1 or 2 with 1 to 3 seedlings of the 3 or 4 types of reaction	5	10
III......	Predominance of 1 or 2 with more than 3 seedlings of 3 or 4 types of reaction	16	22
IV.......	Approximately equal numbers of 1 or 2 and 3 or 4 types of reaction	4	7
V........	Predominance of 3 or 4 with more than 3 seedlings of 1 or 2 types	0	5
VI.......	Mostly 3 or 4 with 1 to 3 seedlings of the 1 or 2 types	0	1
VII......	Breeding true to the 3 or 4 types of reaction	113	87
VIII.....	All showing "x" type of reaction	11	0
	Total............................	192	192

It was interesting to note that a number of lines gave from one to many off-type reactions. The heterogeneity of the lines falling in classes II and VI possibly could be explained as a result of an occasional natural cross or may be due to mechanical mixture. A study of seedling reaction to individual forms of stem rust appears to be a very desirable and practical method of testing for homozygosity of individual lines. It seems reasonable to conclude that lines falling in classes III, IV, and V should be reselected.

SUMMARY

1. The inheritance of ligule has been explained on the basis of two pairs of dominant duplicate factors.

2. The inheritance of reaction to a collection of physiologic forms of stem rust, as studied in the F_3 lines of a cross between Hope, a highly resistant variety, and Liguleless, a highly susceptible variety, has been explained on the basis of a dominant factor for resistance, R, carried by the Hope parent and an inhibitory factor, I, carried by the Liguleless parent, which, in the presence of R, gives susceptibility.

3. In the study of F_3 lines of a cross between Ceres x Hope, a resistant variety, and Ceres x D. C., a moderately resistant variety, it was found that the Hope type of resistance was differentiated by a single factor pair.

4. While studying the effect of types of rust on the yielding ability of the plant, it was observed that, although the average yield of semi-resistant plants was slightly higher than the average yield of resistant plants, the difference was not statistically significant, as tested by Fisher's analysis of variance method. This result reveals the fact that other factors determining yield are playing such a strong part that it was not possible to demonstrate that the different categories of rust reaction had an effect on yield.

5. In the study of plumpness of seed in the same cross, it was evident that the semi-resistant type of rust brings about more shrivelling than the resistant type. But the variation of seed plumpness as brought about by different percentages of rust within the semi-resistant group was not significant. This may be due to the fact that after a particular limit any amount of increase in rust does not effect a significant increase in shrivelling. The variation in seed plumpness within the resistant group due to varying amounts of rust was quite significant. Class 7 with more rust resulted in a decided increase in shrivelling of the grain when compared with the effects of rust classes 8 or 9. Plumpness of kernel is an important character of seed in wheat, being closely associated with yield and also is an important factor in determining the market value of the grain. Hence, though the semi-resistant type of rust reaction has not reduced the yield in a demonstrable manner, yet it has decidedly affected the plumpness of the grain.

6. From a total of 192 hybrid lines that appeared relatively homozygous and that were tested to determine their type of seedling reaction to one or both of the physiologic forms used, 70 lines gave genotypic variation. On the basis of these results it was suggested that 54 lines with the greatest number of variant seedlings should be reselected.

LITERATURE CITED

1. AAMODT, O. S. The inheritance of growth habit and resistance to stem rust in a cross between two varieties of common wheat. Jour. Agr. Res., 24 : 457–469. 1923.
2. ———. Breeding Wheat resistant to physiologic forms of stem rust. Jour. Amer. Soc. Agron., 19 : 206–218. 1927.
3. EMERSON, R. A. The inheritance of ligule and auricles of corn leaves. Nebr. Agr. Exp. Sta. Rpt., 25 : 81–88. 1912.
4. FISHER, R. A. Statistical Methods for Research Workers. London : Oliver and Boyd. Ed. 4. 1933.
5. GOULDEN, C. H. Breeding rust resistant varieties of wheat. Fundamental aspects of the problem. Sci. Agr., 10 : 258–267. 1929.
6. ———, and GREANEY, F. J. The relation between stem rust infection and the yield of wheat. Sci. Agr., 10:405–410. 1930.
7. ———, NEATBY, K. W., and WELSH, J. W. The inheritance of *Puccinia graminis tritici* in a cross between two varieties of *Triticum vulgare*. Phytopath., 28 : 631–657. 1928.
8. HARRINGTON, J. B., and SMITH, W. K. The inheritance of reaction to black stem rust of wheat in a Dicoccum and Vulgare cross. Can. Jour. Res., 2 : 163–188. 1929.
9. HAYES, H. K., and AAMODT, O. S. A study of rust resistance in a cross between Marquis and Kota wheats.
10. ———, AAMODT, O. S., and STEVENSON, F. J. Correlation between yielding ability, reaction to certain diseases and other characters in spring and winter wheat in rod row trials. Jour. Amer. Soc. Agron., 19 : 896–909. 1927.

11. ————, STAKMAN, E. C., and AAMODT, O. S. Inheritance in wheat of resistance to black stem rust. Phytopath., 15 : 371–387. 1925.
12. LOVE, H. H., and CRAIG, W. T. Small grain investigations. Jour. Her., 9 : 67–76. 1918.
13. MATSURA. Bibliographical monograph on plant genetics. Hokkaido Imperial University, 1900–1929. 1933.
14. NEATBY, K. W., and GOULDEN, C. H. The inheritance of resistance to *Puccinia graminis tritici* in crosses between varieties of *Triticum vulgare*. Sci. Agr., 10 : 398–404. 1930.
15. SNEDECOR. Calculations and interpretation of analysis of variance and covariance. Ames, Iowa: Collegiate Press, Inc. 1934.
16. STAKMAN, E. C., and LEVINE, M. N. The determination of biological forms of *Puccinia graminis* on *Triticum* spp. Minn. Agr. Exp. Sta. Bul. 8. 1922.

PALE, AN HEREDITARY CHLOROPHYLL DEFICIENCY IN BEANS[1]

FRANCIS L. SMITH[2]

Chlorophyll-deficient types in beans have not been numerous. In most cases they are spontaneous and behave like mutations. That these deficient types have been reported mostly in hybrid progeny may be due to the fact that such progeny rows are given more detailed attention and the deficient types are thus more apt to be recognized. Burkholder and Muller (1)[3] noted an hereditary deformity of the leaf resembling mosaic. It behaved as a recessive and reappeared in the F_2 in the ratio of 15 normal to 1 pseudomosaic. This was found in a selection of White Marrow x Flat Marrow.

Johannsen (2) found an albino "bud mutation" in a pure line of beans. The albino seedlings were unable to live long.

Tjebbes and Kooiman (5) observed a line of beans which regularly segregated a few albino seedlings. By grafting a seedling on a normal green stock they were able to get it to mature seed. All the seed from the albino scion produced albino plants. However, the scion developed some chlorophyll in certain areas of the leaves, so that it was not entirely colorless. Lines heterozygous segregated the albino seedlings in the ratio of 3 green to 1 albino.

Parker (3) encountered in a selection from Green Refugee x Well's Red Kidney a row in which all plants had yellow spotted leaves. The plants were able to reach maturity and produce seed. Attempts to establish the abnormality as due to a virus disease failed. In crossing the yellow spot to normal plants the F_1 plants were somewhat spotted and the F_2 segregated in the ratio of 1 green to 2 intermediate spotted to 1 intense spotted. The author proposed the symbol Y-y to represent the gene which is at least partially dominant.

PALE MUTANT

The pale mutant was noticed first in a row of beans from a single plant selection of a white-seeded family of Robust x Pink. Two plant

[1] Contribution from the Division of Agronomy, University of California, Berkeley, Calif. Received for publication June 29, 1934.
[2] Junior Agronomist.
[3] Figures in parenthesis refer to "Literature Cited," p. 897.

selections were made in 1930 from the same row and planted in 1931. One produced normal green plants and the other all pale green. All plants in the row were paler green than normal. No notes are available as to the occurrence in 1930.

The plants are apparently normal in habit of growth and in seed characters. It is a white-seeded selection, very much like Robust in size and shape. The pale plants are easily recognized in the early stages of plant growth in the field and the difference is maintained until near maturity, when the leaves of all varieties turn yellow. An effort was made to make accurate color determinations from greenhouse-grown plants in 1933–34. Some difficulty was encountered in classifying plants after they were 4 to 6 inches high. In early stages, however, the cotyledon leaves were somewhat paler. By Ridgway's (4) color standard the normal leaves are forest green, 29 m, and the pale leaves are spinach green, 29 m.

Four rows of the mutant were harvested in 1933. The average yield was 430 grams per row, or 830 pounds per acre. Four rows of Robust grown in an adjacent plat had an average yield of 1,805 grams, or 3,460 pounds per acre. The reduction in yield is very likely caused by the deficiency. The size and shape of the beans are very similar. The index (weight of 100 beans in grams) of the pale averaged in the four rows 23.1, while the four rows of Robust had an average index of 22.1. This difference is hardly significant.

GENETIC BEHAVIOR

A number of reciprocal crosses were made between the variety Robust and the pale selection in 1931 to test the genetic behavior of the chlorophyll deficiency.

The F_1 generation was grown in short rows in the bean nursery in 1932. The hybrid plants were all green, indicating that pale is a recessive character. A detailed record of the F_1 plants is shown in Table 1.

The second generation was grown in 20-foot rows in 1933. The behavior of F_2 plants is given in Table 2. The pale plants were fewer than expected, the D/E being 3.86. The deficiency of pales may be due to the fact that some pale plants were overlooked in counting the F_2 rows. The formula used for testing goodness of fit is $P. E. = .6745 \sqrt{PQN}$, when P and Q are expressed as a decimal fraction and N the number in the population. In case of a 3 : 1 ratio, $P. E. = .6745 \sqrt{.75 \times .25 \times N}$. We do not believe that the pale is semi-lethal, although the data on yield indicate it is somewhat depressed by the lack of chlorophyll.

To test further the hypothesis that the chlorophyll deficiency is due to a single gene mutation, a number of plants from F_2 rows were grown in the greenhouse in 1933–34. Twenty seeds were sown from each plant in a 10-inch pot and counts were made on the color of seedlings. The data of the F_3 progenies are presented in Table 3.

If the pale condition is due to one factor, all pale F_2 would be expected to breed true. Seven pale progenies were tested from all five crosses and all bred true. We should expect one-third of the progenies from green F_2 plants to breed true for green and two-thirds to

TABLE 1.—*Behavior of F_1 plants of pale x Robust and reciprocal.*

Cross	Cross No.	1932 row	Number of F_1 plants	Color
Robust x pale	31.094	95	3	Green
Robust x pale	31.095	98	2	Green
Robust x pale	31.096	101	3	Green
Robust x pale	31.097	104	3	Green
Pale x Robust	31.098-a	107	2	Green
Pale x Robust	31.098-b	110	4	Green
Pale parent		6 rows	..	All pale
Robust parent		6 rows	..	All green

TABLE 2.—*F_2 data of Robust x pale and reciprocal*

Cross	Cross No.	Row	Number of plants green	Number of plants pale
Robust x pale	31.094–1	138 139	72	21
Robust x pale	31.094–2	140	6	1
Robust x pale	31.094–3	141	19	10
Total			97	32
Robust x pale	31.096–1	148	44	15
Robust x pale	31.096–2	149	33	13
Robust x pale	31.096–3	150	16	2
Total			93	30
Robust x pale	31.097–1	153 154	67	19
Robust x pale	31.097–2	155	24	2
Robust x pale	31.097–3	156	42	7
Total			133	28
Pale x Robust	31.098a–1	159	43	11
Pale x Robust	31.098a–2	160 161	59	15
Total			102	26
Pale x Robust	31.098b–1	164	27	9
Pale x Robust	31.098b–2	165	54	7
Pale x Robust	31.098b–3	166	44	10
Pale x Robust	31.098b–4	167 168	69	22
Total			194	48
Total: Robust x pale			323	90
Expected 3:1			309.75	103.25
D = 13.25 E = 6.0				D/E = 2.2
Total: Pale x Robust			296	74
Expected 3:1			277.50	92.50
D = 18.5 E = 5.6				D/E = 3.3
TOTAL			619	164
Expected 3:1			587.25	195.75
D = 31.75 E = 8.2				D/E = 3.86

TABLE 3.—*Behavior of F_3 seedlings from F_2 plants tested in the greenhouse, 1933–34.*

Cross	Cross No.	Progeny from green F_2 plants					Progeny from F_2 pale plants	
		True breeding green		Segregating green and pale				
		Plants tested	Number of F_3 green seedlings	Plants tested	Number of F_3 seedlings		Plants tested	Number of F_3 pale seedlings
					Green	Pale		
Robust x pale.....	31.094	1	19	6	111	41	3	77
Robust x pale.....	31.096	2	37	4	53	22	1	6
Robust x pale.....	31.097	2	38	3	47	12	1	20
Pale x Robust.....	31.098a	3	58	2	30	9	1	20
Pale x Robust.....	31.098b	3	60	3	41	16	1	18
Total.....	....	11	212	18	282	100	7	141
Expected..	....	9.67	212	19.33	286.5	95.5	7	141

Progeny for F_2 green plants:
Expected: 1 homozygous green: 2 heterozygous green, or 9.67:19:33
Observed: 11 :18
$D = 1.33$ $E = 1.71$ $D/E = 0.78$
Progenies from heterozygous green F_2 plants:
Expected: 3 green: 1 pale, or 286.5: 95.5
Observed: 282 :100 $D = 4.5$ $E = 5.64$ $D/E = 0.80$
Progenies from homozygous green F_2 plants:
Expected: All green
Observed: 282 all green
Progenies from pale F_2 plants:
Expected: All pale
Observed: 141 all pale

segregate 3 green to 1 pale. Twenty-nine progenies were tested of which 11 were pure green and 18 segregated green and pale. The expected numbers are 9.67 : 19.33. This is a very good fit. Of the segregating progenies, 282 green plants and 100 pale were obtained. The expected ratio is 286.5 : 95.5 This, too, is a very good fit. The F_3 progeny tests thus fulfill all expectations for a single gene mutation.

The author proposes the symbol pa to designate the pale condition and *Pa* the normal dominant allelomorph.

This stock may be used in further studies of linkage.

SUMMARY

A pale mutant row of beans was found in a selection of white-seeded Robust x Pink. The pale plants have lighter colored leaves than normal. The pale plants yield about one-fourth as much as the normal green Robust variety; however, there is no mortality in germination.

The F_1 plants from pale x Robust and reciprocal are green. The F_2 plants segregate 3 green: 1 pale. The pales were generally fewer than expected in the field. The F_3 progeny from pale plants bred true. One-third of the F_3 progeny from green plants bred true, two-thirds segregated 3 green: 1 pale.

The conclusion is drawn that the pale condition is controlled by a single recessive gene, *pa*, which has the normal allelomorph, *Pa*, in the Robust variety.

LITERATURE CITED

1. Burkholder, W. H., and Muller, A. S. Hereditary abnormalities resembling certain infectious diseases in beans. Phytopath., 16 : 731–737. 1926.
2. Johannsen, W. Uber Knospenmutation bei Phaseolus. Zschr. ind. Abst. und Vererb., 1 : 1–10. 1909.
3. Parker, M. C. The inheritance of a yellow-spot character in the bean. Jour. Her., 24 : 481–487. 1933.
4. Ridgway, Robert. Color Standards and Nomenclature. 1912.
5. Tjebbes, K., and Kooiman, H. N. Erfelijkheidsonderzoekingen bij boonen. III. Albinisme. (With English summary). Genetica, 1 : 532–538. 1919.

AGRONOMIC AFFAIRS

TWENTY-SEVENTH ANNUAL MEETING OF THE SOCIETY

The twenty-seventh annual meeting of the Society will be held on November 22 and 23 at the Wardman-Park Hotel in Washington, D. C. A joint meeting of both Sections of the Society is scheduled for the morning of Thursday, November 22. At that time a program will be presented dealing with the relationship of pastures and pasture grasses to the national land utilization program, including the following papers:

1. Economic Aspects of Pastures in the Land Planting Program. C. L. Holmes, Bureau of Agricultural Economics, U. S. Dept. of Agriculture.
2. Relation of Grass Covering to Erosion Control. H. H. Bennett, U. S. Dept. of the Interior.
3. Pasture Grass Areas in the United States. H. N. Vinall, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture.

Sessions of the Soils and Crops Sections of the Society will be held Thursday afternoon and Friday. Since detailed programs will be mailed to all members of the Society from the Secretary's office, only tentative outlines of the programs for the two Sections are presented at this time.

SOILS SECTION

PROBABLY THURSDAY AFTERNOON

Business session for election of officers and transaction of general business.

Joint meeting of American members of the International Society of Soil Science, the American Soil Survey Association, and the Soils Section of the American Society of Agronomy to consider report of

Reorganization Committee. Additional suggestions have been made since the report of this Committee was printed in the September issue of the JOURNAL, and it is hoped that a large representation from each of the three societies will be present.

Business meeting of American members of International Society of Soil Science to pass on proposed organization.

THURSDAY AFTERNOON

Joint session of American Soil Survey Association and the Soil Chemistry Subsection.
Subject: The Processes and Products of Soil Weathering.
Joint session of Crops Section and the Soil Fertility Subsection.
Subject: Pasture Fertilization and Management.

FRIDAY MORNING

Joint session of Soil Chemistry and Soil Fertility Subsections.
Subject: Factors Affecting the Availability of Natural and Applied Phosphates.
Soil Biology Subsection.
Subject: Organic Matter Decomposition in the Soil.

FRIDAY AFTERNOON

Soil Fertility Subsection. Miscellaneous papers.
Soil Biology Subsection.
Subject: Microbiological Activities and the Root Environment.
Soil Physics Subsection.
Subject: Interfacial Relationships in Soils.

CROPS SECTION

The program for the Crops Section will place special emphasis on problems concerned with pasture plants, production, and management. For those especially interested in this phase of agronomic work, papers of interest can be heard continuously from the general combined session of the entire Society on Thursday morning to the closing paper Friday afternoon.

A joint session with the Soil Fertility Subsection of the Soils Section, dealing with problems of common interest to the two groups, has been arranged for Thursday afternoon to be followed on Friday by papers dealing with more specific crops pasture problems. Environmental, physiological, and inheritance problems with crops will be treated in a full program on Thursday afternoon.

A total of 34 papers on a variety of subjects with special emphasis on pasture problems assures an interesting and instructive program for every member of the Society. A detailed printed program will be available to members at an early date.

An informal discussion of the nomenclature appropriate for designation of double crosses of corn with the various problems involved has been suggested. This could be arranged possibly for Friday afternoon if sufficient interest is manifest.

RAILROAD RATES

A special railroad rate of one fare and a third, on the certificate plan, has been granted for the following meetings at Washington, November 16–24, 1934:

Association of Land-Grant Colleges and Universities, Nov. 19–21
American Country Life Association, Nov. 16–19
Association of State Universities, Nov. 21–23
American Society of Agronomy, Nov. 22–23
American Soil Survey Association, Nov. 20–21

All persons attending these meetings are urged to obtain a certificate at the time of purchasing railroad fare to Washington. A minimum of 100 certificates is required to make the special rate available. If made effective, it will result in a considerable saving in the travel expense, especially for those attending from the more distant states.

Selling dates for the special rate are as follows:

Central Passenger and Trunk Line Associations	Nov. 13–19
East of and including Chicago and St. Louis north of the Ohio and Potomac Rivers to the Atlantic Seaboard south of New England and Canada.	
New England Passenger Association:	Nov. 13–19
Southeastern Passenger Association:	Nov. 13–19
Southwestern Passenger Association:	
Oklahoma and Texas	Nov. 12–18
Arkansas, Kansas, Louisiana, Missouri, also Memphis, Tenn. and Natchez, Miss	Nov. 13–19
Transcontinental Passenger Association Western Passenger Association	
Colorado (Julesburg only), Illinois, Iowa, Kansas, Manitoba (see note), Minnesota, Missouri, Nebraska, Nor. Michigan, No. Dakota, So. Dakota and Wisconsin	Nov. 13–19
Colorado (except Julesburg) and Wyoming	Nov. 12–18
Montana and Southern Idaho	Nov. 11–17
Arizona, British Columbia, California, Nevada, New Mexico, Northern Idaho, Oregon, Utah and Washington.	Nov. 3–18

NOTE:—Manitoba (on Grt. Nor., Nor. Pac. and MStP&SSM Rys; also from Winnipeg via Can. Nat. and Can. Pac. Rys).

A special agent will validate the certificates on November 19–23, inclusive. Validated certificate *must* be presented to ticket agent for purchase of return ticket at one-third fare not later than November 28. Ticket so purchased will be good for return passage to reach original starting point within 30 days in addition to date of sale of going ticket, via same route as used on the going journey. When purchasing your going ticket, request a CERTIFICATE from the ticket agent.

TOBACCO FERTILIZER RECOMMENDATIONS FOR 1935

The Tobacco Research Committee of Virginia, North and South Carolina, and Georgia has prepared recommendations for the fertilization of flue-cured, sun-cured, and shipping tobacco grown on average soils in those states for the year 1935. Also attached to the Committee Report are suggestions to agricultural workers for use in formulating recommendations for the control of downy mildew and root-knot of tobacco prepared by a representative group of plant pathologists. The report is in mimeographed form and may be obtained through Professor C. B. Williams of the North Carolina Experiment Station, Raleigh, N. Car., Chairman of the Tobacco Research Committee.

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EFFECT OF SUDAN GRASS AND OF SOYBEANS ON YIELD OF CORN[1]

F. S. WILKINS AND H. D. HUGHES[2]

It is a matter of common observation that under certain conditions crops following sudan grass and other species of the sorghum group yield less than when they follow other commonly grown farm crops. Furthermore, experimental evidence confirming this general observation is plentiful. Apparently, it is generally agreed that depressed yields following sorghum and related species are more likely to occur on soils deficient in nitrogen.

Also, experimenters are in agreement that less benefit to succeeding crops is to be expected when soybeans are grown and the crop removed than when such crops as red or sweet clover or alfalfa with larger root growths are included in the rotation.

This paper gives the yields of corn following sudan grass and soybeans as compared with yields following oats as check through a 14-year period at the Iowa Experiment Station. Comparative yields of corn after fall and after spring plowing of sudan grass stubble also are reported. Since but one soil type and one fertility level are represented in these tests, the literature is briefly reviewed.

REVIEW OF LITERATURE

SUDAN GRASS

The reason for depressed yields following sudan grass and related plants which occur under certain conditions and not under others is still being discussed and investigated. Breazeale (1)[3] interpreted the results of his experiments as indicating that toxins, remaining temporarily in the soil following the sorghums, are responsible. Several other experimenters have rejected the toxin theory.

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[1] Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 188. Journal Paper No. J181 of the Iowa Agricultural Experiment Station. Received for publication June 28, 1934.

[2] Research Assistant Professor and Professor of Farm Crops, respectively. Statistical calculations were made in the Statistical Laboratory, Iowa State College, under the direction of Professor George W. Snedecor, Statistician of the Iowa Agricultural Experiment Station. Analysis of variance methods as outlined by Fisher (6) and Snedecor (20) were used. The following men in order assisted in collecting the data from 1919 to 1933, inclusive: Ove F. Jensen, E. A. Hollowell, David Heusinkveld, H. L. Hyland, and L. D. Eagles.

[3] Reference by number is to "Literature Cited," p. 908.

Conrad (2, 3, 4) has presented rather convincing evidence to support his belief that crops yield less following the sorghums because of a shortage of nitrates. He and others have shown that because the sorghum roots and stubble are high in readily oxidizable carbohydrates, the multiplication and growth of micro-organisms are stimulated with the result that the soil is temporarily depleted in available nitrogen. Wilson and Wilson (22) interpreted their results as supporting Conrad's belief. On the other hand, while Gainey (7) and McKinley (17) observed a greater immediate decrease in available nitrogen when kafir and sorghum, respectively, were incorporated with the soil than when corn was used similarly, they believed that the effect was too temporary to account for the greatly depressed yields following the sorghums which are often reported.

Depletion of soil moisture has been suggested as the cause, but Conrad (4) demonstrated depressed yields following sorghum on irrigated plats, while Sewell (19) found that wheat yielded less following kafir than following corn when grown in the greenhouse under controlled moisture conditions.

Breazeale (1) noted deflocculation of soils which had grown sorghum and recommended plowing under the sorghum stubble as soon as possible after harvest as a means of correcting the poor physical condition and to eliminate the toxins as quickly as possible. Hawkins (11) stated that any amount of work on the soil would not rectify its poor physical condition following the growing of sorghum. Hughes and Wilkins (14) observed that sudan grass left the soil in poor physical condition and stated that fall plowing was a helpful corrective.

SOYBEANS

On nitrogen-deficient soils with minerals added, Lyon (15) obtained an increase of 65% in the yields of barley and of rye when these crops followed soybeans, as compared with oats or rye as the preceding crops. However, increases obtained when red, alsike, or sweet clover or alfalfa were the preceding crops were about three times as great. All crops were removed in these comparisons.

As averages of rotations which included corn, soybeans, wheat, clover, and timothy, Wiancko and Mulvey (21) obtained 30.6 bushels per acre of wheat following soybeans which had been removed as compared with 24.5 bushels following corn. They evidently maintained the nitrogen content of their soils with clover in these rotations. Hill (13) alternated soybeans and wheat and increased the yield of wheat from 16 to 21 bushels per acre when the soybeans were cut for hay and to 26 bushels when the beans were plowed under. The check yield of 16 bushels apparently was obtained with wheat following wheat. Grantham (9) reported that soybeans seem to leave the land in ideal condition for large yields of wheat.

Workers (5) at Cornell University found that winter wheat started sooner after soybeans but yielded approximately the same as after oats.

Mooers (18) obtained an average yield of 35.5 bushels of corn per acre where soybeans, which were removed, were alternated with corn as compared with 27.1 bushels for continuous corn in the same years. The differences were greater during the last 2 years of a 10-year test. Plowing soybeans under increased the yield of corn to 39.7 bushels. In another location, with better soil, soybeans did not increase the corn yields appreciably during the first 5 years.

McClelland (16) obtained an increase from 35 bushels of corn per acre where corn followed oats to 44 bushels following soybeans in 1922, but corn following the same two crops in 1924 yielded similarly. Plowing under the soybeans increased the yield of corn 12% over removing for hay in 1922 and 16% in 1924. Hackleman, *et al.* (10) reported that corn the first year after soybeans yielded 20% more than corn the third year after soybeans and 10% more than corn the second year after soybeans in a 4-year rotation of corn, corn, corn, and soybeans.

Grantham (8) stated that soybeans are very exhaustive of the soil and that in some cases yields of corn were 25 bushels per acre less in a rotation including soybeans and timothy than in a rotation including clover.

Hill (13) found that when soybeans were removed for hay the reserve nitrogen of the soil was not increased, but when the crop was turned under it was markedly increased. Workers (5) at Cornell University reported that when soybeans were removed early there was an increase in the nitrate content of the soil in the fall and a decrease in the spring which resulted in high yields of wheat and low yields of corn, while late removal of soybeans had an opposite effect. The depressing effect of late removal of soybeans on yield of wheat was overcome by the application of sodium nitrate at the time of seeding the wheat.

METHODS OF COMPARISON

Sudan grass, soybeans, and oats were compared as preceding crops for corn during the period of 1919 to 1933. Six adjacent, 1/20 acre plats were used. Oats, sudan grass, and soybeans were grown on plats 1, 2, and 3, respectively, in odd years and on plats 4, 5, and 6, respectively, in even years. Corn was grown on plats 1, 2, and 3 in even years and on plats 4, 5, and 6 in odd years.

The soil, O'Neill sandy loam, had been cropped uniformly for several years previous to beginning the test in 1919 and was considered to be unusually uniform and sufficiently fertile to produce 50 to 60 bushels of corn per acre in an average season. The soil is underlaid with sand and gravel at a depth of about 5 feet so that yields were greatly reduced in dry years. In 1930 corn was a complete failure, except for a comparatively small growth of stalks, because of the most severe drouth ever recorded at Ames.

All crops were removed except the corn stalks and such of the fallen soybean leaves as had not blown away before plowing. Two crops of sudan grass hay were obtained per season. Soybeans and oats were harvested for grain, with one exception for beans and two for oats when hay yields were taken. No manure or fertilizer was used except, beginning in 1929, 20% superphosphate was applied at the rate of 200 pounds per acre to one-half of each plat cropped to corn.

The phosphate was applied near but not in the hills at corn planting time. It is believed the soil was well supplied with other minerals.

Corn was grown in three- or four-stalk hills, 3 by 3½ feet, five rows per 15-foot plat, with the two outside rows discarded as borders. The usual precautions were taken to obtain satisfactorily uniform stands. All yield comparisons were made on an air-dry basis during the early years and on a water-free basis, raised to 14%, during the later years. Soybeans were well inoculated from the beginning. They were usually grown in 30-inch rows, but sometimes in 8-inch rows. In preparation for all crops the land was plowed in late October or early November.

The test was concluded in 1933 when corn was grown on both series of plats. Thus, corn followed corn on one series in this one year. While conditions for uniform comparisons in 1933 appeared to be favorable, corn yields were much less than they would have been had the same source of seed been used as in other years. In all other years corn yields were closely associated with amount and distribution of rainfall and reserve soil moisture.

Tests were conducted in 1928, 1929, 1930, and 1932 to determine whether higher yields of corn may be expected from the fall plowing than from the spring plowing of sudan grass stubble. Good crops of sudan grass were grown in the same field and on the same soil type as for the test previously described. The soil had been manured and legume residues had been plowed under occasionally in previous years so that the soil was in a good state of productivity. In preparation for corn the sudan grass stubble of alternate 17.5- by 52.5-foot plats was plowed under in October and in April with a two-way plow. Spring-plowed plats were finished on the back furrow of fall-plowed plats so that the soil was left level when disked and harrowed. Corn was planted in 3.5-foot hills with rows on the plat lines, leaving four rows for yield determinations after removing borders. End hills also were removed as borders. The same precautions to obtain uniform stands and yields as described for the previous test were used. Practically perfect stands account in part for the high yields obtained. The test was well replicated to insure accurate results. Sixteen plats were used in each of the years 1928 and 1930 and 20 plats in each of the years 1929 and 1932.

RESULTS

SUDAN GRASS, SOYBEANS, AND OATS AS PRECEDING CROPS FOR CORN

The yields of corn following sudan grass, soybeans, and oats are shown in Table 1. The average yields for 1920–33 were 50.8 bushels per acre following sudan grass, 49.0 bushels following soybeans, and 47.8 bushels following oats.

Beginning in 1929, superphosphate applied to one-half of each plat at the time of planting corn did not change the order. For the period of 1929–33, with no fertilizer treatment, the corn yielded 39.2 bushels per acre following sudan grass, 35.8 bushels following soybeans, and 34.2 bushels following oats. With superphosphate applied, the corn yielded 32.6 bushels per acre following sudan grass, 31.7 bushels ollowing soybeans, and 29.5 bushels following oats. The fact that the ends of plats to which superphosphate was applied yielded less is of no significance since the divisions were not adjacent the long way. All averages include the yields for the even year plats planted to corn in 1933 instead of to sudan grass, soybeans, and oats in concluding the test.

TABLE 1.—*Yields of corn in bushels per acre following sudan grass, soybeans, and oats, 1920-33.*

Year	No treatment			Superphosphate applied at corn planting time		
	Sudan grass	Soybeans	Oats	Sudan grass	Soybeans	Oats
1920	66.7	74.0	64.1	—	—	—
1921	40.8	34.6	42.9	—	—	—
1922	90.8	69.5	80.7	—	—	—
1923	58.7	68.3	52.6	—	—	—
1924	41.6	42.8	41.8	—	—	—
1925	70.9	66.4	65.2	—	—	—
1926	62.3	58.9	61.8	—	—	—
1927	17.8	17.5	14.1	—	—	—
1928	65.4	75.0	75.4	—	—	—
1929	37.1	48.5	39.5	34.1	42.2	44.4
1930*	—	—	—	—	—	—
1931	19.7	14.8	16.0	16.2	16.1	10.7
1932	80.3	60.3	61.5	65.5	54.9	50.2
1933	26.8	27.8	26.6	22.1	26.9	20.9
1933†	32.1	27.6	27.6	25.1	18.2	21.2
Av., 1920-33	50.8	49.0	47.8	—	—	—
Av., 1929-33	39.2	35.8	34.2	32.6	31.7	29.5

*Failed because of drouth.

†Corn grown instead of sudan grass, soybeans, and oats in concluding the test.

Two separate calculations for analysis of variance, one for no fertilizer treatment 1920-33 and the other for the combination of no fertilizer treatment and superphosphate applied 1929-33, showed that the differences indicated, including the averages, are not statistically significant. While differences for individual years are large in some cases, owing, no doubt, to the fact that each yield is that of an individual plat, the differences are not consistently in favor of any one of the three crops. Thus, for the no fertilizer treatment series 1920-33, the highest corn yield exceeded the lowest by 24% or more for 7 of the 14 comparisons. For these 7 years, 1921-23, 1927, 1929, 1931, and 1932, sudan grass as the preceding crop gave the highest yields of corn four times, soybeans twice, and oats once. For all of the 14 comparisons sudan grass was superior seven times, soybeans five times, and oats twice. For the superphosphate series all differences between the highest and lowest corn yields were 29% or more, but for the five comparisons sudan grass as the preceding crop for corn was superior three times, soybeans once, and oats once.

In reporting the results of this same test for the first 6 years, in 1926, Hughes and Wilkins (14) suggested that shortage of water might be a factor contributing to cause lower yields following sudan grass under certain conditions. However, it would seem that this is not tenable since in the two very dry years of 1927 and 1931, when corn in this test yielded about one-third of a crop, it yielded more following sudan grass than following soybeans or oats. The fact that corn actually yielded more following sudan grass in both dry years may be due to chance. However, the results support the evidence of Conrad (4) and Sewell (19) which indicate that at least under certain conditions water is not the limiting factor to account for lower yields following crops of the sorghum group.

The total amounts of dry matter and nitrogen removed by sudan grass, soybeans, and oats from 1919 to 1932 inclusive are shown in Table 2. The figures for nitrogen are approximate since no analyses were made and percentages given by Henry and Morrison (12) were used.

TABLE 2.—*Total amounts of dry matter and of nitrogen removed by sudan grass, soybeans, and oats, 1919–32.*

Crop	Years in corn	Produce, lbs. per acre				Nitrogen, lbs. per acre			
		Grain	Straw	Hay	Total	Grain	Straw	Hay	Total
Sudan grass. .	Even	—	—	49,480	49,480	—	—	648	648
	Odd	—	—	48,980	48,980	—	—	642	642
Soybeans. . . .	Even	6,723	8,487	2,454	17,664	393	76	63	532
	Odd	8,446	13,165	—	21,611	493	118	—	612
Oats.	Even	8,027	9,660	3,000	20,687	159	56	40	255
	Odd	8,124	9,592	4,735	22,451	161	56	63	280

Sudan grass produced over twice as much dry matter as the other two crops and removed over twice as much nitrogen as the oats and appreciably more than the soybeans. Also, it must be recognized that a certain percentage of the nitrogen removed by the soybeans came from the air, even though the soil was relatively fertile. However, despite these heavier withdrawals of nutrients by sudan grass, it appears from corn yields obtained in 1932–33 (Table 1) that the soil of the sudan grass plats was just as productive after the 13 years of cropping as that of the soybean and oat plats.

FALL VS. SPRING PLOWING OF SUDAN GRASS STUBBLE FOR CORN

As an average for the 4 years, the fall-plowed sudan grass plats yielded 68.3 bushels per acre, or 4.4 bushels or 10.7% more than the spring-plowed plats (Table 3). Analysis of variance calculations indicate that this difference is highly significant, and therefore, that higher yields may be expected following fall plowing than spring plowing under similar conditions.

About the same percentage increase from fall plowing was obtained in each of the last 3 years, *viz.*, 11.1% in 1929, 10.9% in 1930, and 11.4% in 1932. Because of unusually favorable moisture conditions in 1928, high yields were obtained, 97.2 bushels per acre after fall plowing and 98.9 bushels after spring plowing. The decrease of 1.7% for fall plowing is not significant.

The authors recognize the fact that rather extensive comparisons of fall and spring plowing for different crops and on widely different soils have shown little or no advantage for either fall or spring plowing.

TABLE 3.—*Yields of corn in bushels per acre following fall and spring plowing of sudan grass stubble, 1928–32.*

	1928	1929	1930	1932	Average
Fall plowed	97.2	71.3	30.0	74.5	68.3
Spring plowed	98.9	64.0	27.5	65.2	63.9
Difference*	—1.7	7.3	2.5	9.3	4.4
Increase, %*	—1.7	11.1	10.9	11.4	10.7
Number of replications	8	10	8	10	—

*In favor of fall over spring plowing.

Differences in soil moisture content of samples collected from the different plats during the dry year of 1930 when the rainfall of June, July, and August was only 77%, 13%, and 25% of normal, respectively, were not significant. A total of 137 samples representing surface soil, subsurface soil, and subsoil were taken at bimonthly intervals between May 15 and November 15.

DISCUSSION

While corn yielded equally well following sudan grass, soybeans, and oats on this black, fertile soil, entirely different results might be expected on soils low in nutrients, particularly nitrogen. Conrad (4) stated that sorghum growers obtained little if any decrease in yields of wheat following sorghum on very fertile soils.

Also, since the soil was fall plowed with a lapse of several months before corn was planted, the cause of any deleterious effect which might have induced decreased yields with a shorter interval was given time to disappear. The fact that corn yielded more following fall plowing of the sudan grass stubble supports this belief. Breazeale (1), who believed that depressed yields following the sorghums are due to toxins; Conrad (2, 3, 4) and others, who believed they are due to more pronounced nitrate shortage because of greater activity of soil microorganisms; and those who believe the injury is due simply to temporary soil exhaustion are agreed that immediate, so-called sorghum injury is temporary.

It is believed that higher proportionate yields of corn following soybeans would have been obtained if the tests had been conducted on nitrogen-deficient soil. From observations the writers have made in southern Iowa it would seem that on soils low in nitrogen but plentifully supplied with other nutrients soybeans are remarkably efficient in utilizing large quantities of nitrogen from the air. Lyon's (15) results can be interpreted as supporting these observations.

Also, if each of the crops harvested in these tests had been fed and the manure applied to the respective plats, it is possible that considerably different results would have been obtained. The effect of the soybeans with this system of management would be expected to be most pronounced on soils most deficient in nitrogen.

SUMMARY

Three 2-year rotations in which sudan grass, soybeans, and oats were alternated with corn were compared between 1919 and 1933, inclusive. All crops were removed except corn stalks and some fallen soybean leaves. On O'Neill black fertile soil corn yielded 50.8 bushels per acre after sudan grass, 49.0 bushels after soybeans, and 47.8 bushels after oats. The differences are not statistically significant.

The results were not changed by superphosphate applied at corn planting time to half of each plat in the later years. It is believed the soil was well supplied with other minerals.

Sudan grass removed over twice as much dry matter as soybeans or oats, over twice as much nitrogen as oats, and appreciably more than soybeans. Despite these heavier withdrawals the sudan grass plats appeared to be just as productive after 13 years of cropping as the soybean and oat plats.

On soil similar to that used for the other test, fall plowing sudan grass stubble increased the yield of corn 10.7% over spring plowing.

Yields obtained in dry years and water determinations of the soil indicate that moisture deficiency is not a cause of the depressed yields sometimes obtained following sudan grass.

LITERATURE CITED

1. BREAZEALE, J. F. The injurious after-effects of sorghum. Jour. Amer. Soc. Agron., 16: 689–700. 1924.
2. CONRAD, JOHN P. Some causes of the injurious after-effects of sorghums and suggested remedies. Jour. Amer. Soc. Agron., 18: 729–742. 1926.
3. ————. Fertilizer and legume experiments following sorghums. Jour. Amer. Soc. Agron., 20: 1211–1234. 1928.
4. ————. Nitrogenous fertilizers on small grain following sorghums. Jour. Amer. Soc. Agron., 24: 316–322. 1932.
5. Cornell University. Some factors affecting the influence of soybeans, oats, and other crops, on the crops that follow. Cornell Univ. Agr. Exp. Sta. Ann. Rpt., 1930–31: 19. 1931.
6. FISHER, R. A. Statistical Methods for Research Workers. Edinburg: Oliver and Boyd. Ed. 4. 1933.
7. GAINEY, P. L. Relative rates of decomposition of corn and kafir stubble. Jour. Amer. Soc. Agron., 21: 323–343. 1929.
8. GRANTHAM, ARTHUR E. Report of soils and crop investigations. Del. Agr. Exp. Sta. Bul. 122: 10–20. 1918.
9. ————. Crop investigations. Del. Agr. Exp. Sta. Bul. 125. 1919.
10. HACKLEMAN, J. C., SEARS, O. H., and BURLISON, W. L. Soybean production in Illinois. Ill. Agr. Exp. Sta. Bul. 310: 473–478. 1928.
11. HAWKINS, R. S. The deleterious effect of sorghum on the soil and on the succeeding crops. Jour. Amer. Soc. Agron., 17: 91. 1925.
12. HENRY, W. A., and MORRISON, F. B. Feeds and Feeding. Ithaca, N. Y.: Henry-Morrison Co. 1928. (Appendix table III of 19th edition.)
13. HILL, H. H. Decomposition of organic matter in soils. Jour. Agr. Res., 33: 77–99. 1926.
14. HUGHES, H. D., and WILKINS, F. S. Sudan grass. Ia. Agr. Exp. Sta. Bul. 233. 1926.
15. LYON, T. L. The effect of some legumes on the yields of succeeding crops. Cornell Univ. Agr. Exp. Sta. Bul. 447: 8–13. 1925.
16. MCCLELLAND, C. K. Variety and rotation experiments with soybeans. Ark. Agr. Exp. Sta. Bul. 199: 17–18. 1925.
17. MCKINLEY, A. D. Effects of sorghum residues on crop yields. Jour. Amer. Soc. Agron., 23: 844–849. 1931.
18. MOOERS, C. A. Influence of cowpea crop on yield of corn. Tenn. Agr. Exp. Sta. Bul. 137. 1927.

19. SEWELL, M. C. Effect of *Andropogon sorghum* on succeeding crops of *Triticum sativum vulgare*. Bot. Gaz., 75: 1-26. 1923.
20. SNEDECOR, GEORGE W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press, Inc. 1934.
21. WIANCKO, A. T., and MULVEY, R. R. Soybeans in Indiana. Ind. Agr. Exp. Sta. Bul. 238. 1922.
22. WILSON, B. D., and WILSON, J. K. Relation of sorghum roots to certain biological processes. Jour. Amer. Soc. Agron., 20: 747-754. 1928.

EFFECT OF CHEMICAL TREATMENTS OF SEED CORN ON STAND AND YIELD IN KANSAS[1]

LEO E. MELCHERS AND ARTHUR M. BRUNSON[2]

Manufacturers of chemical seed-corn disinfectants claim that treatment with their products will increase yields because of the increases in stand and plant vigor and because of the control of root, stalk, and ear rot diseases. These compounds have been universally recommended for all corn-producing areas in the United States.

The Kansas Agricultural Experiment Station has conducted experiments on the treatment of seed corn over a period of 8 years with the primary purpose of learning (a) what fungous organisms are associated with Kansas seed corn and (b) whether the various advertised commercial seed-corn disinfectants have a beneficial effect on field germination, vigor of plant, final yield, or quality of grain under Kansas conditions.

Some investigators (3, 4, 9)[3] have reported increased yields of corn following corn-seed treatments. Such results have not been obtained by workers (1, 2, 5, 6, 11) in other states. The widely varying conditions in different corn-producing areas of the United States make the drawing of generalized conclusions relative to the influence of any factor extremely hazardous, when data from only a few experimental conditions are available, and indicate the desirability of conducting independent studies with seed-corn disinfection under the different environmental conditions and with the different fungi that are found on seed corn in the various regions.

FUNGOUS ORGANISMS ON KANSAS SEED CORN

Numerous fungous organisms, frequently referred to in literature as "disease organisms," are associated with seed corn. Some of these, under proper soil moisture and temperature conditions, may produce seedling blights, root rots, and ear rots. The presence of some other

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[1] Joint contribution from the Departments of Botany and Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Contribution No. 340 from the Department of Botany and No. 235 from the Department of Agronomy, Kansas Agricultural Experiment Station. Received for publication July 10, 1934.

[2] Head of the Department of Botany, Kansas Agricultural Experiment Station, and Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

[3] Reference by number is to "Literature Cited," p. 917.

fungi is of questionable importance with respect to injuries. It is difficult for the farmer to distinguish between the injurious and non-injurious organisms when the seed is in a germinator or when the organisms are on the plant in the field and on the ear after harvest.

Since two of these fungi, namely, the scab fungus, *Gibberella saubinetii* (Mont.) Sacc., and the dry rot, *Diplodia zeae* Lév., are definitely known to be disease producers, it was imperative to learn how prevalent they were on Kansas seed corn. A third fungus, *Fusarium moniliforme* Sheld., has also been regarded as harmful in some states. However, in the experiments conducted in Kansas, *F. moniliforme* has been found to be of little importance (7). Similar conclusions have been reported for Louisiana (1). Such fungi as *Penicillium* sp., *Rhizopus* sp., *Aspergillus* sp., and others are quite generally associated with seed corn that is somewhat weakened or injured, and under certain environmental conditions some of these may be of importance.

An extensive study of the presence of fungi on Kansas seed corn during the years 1918–24 proved that *G. saubinetii* rarely is present (7, 8, 10). *Diplodia zeae* is more commonly found but usually in small amounts and only in certain sections of the state. Considered over a period of years the injury caused by these organisms in Kansas probably is of comparatively little importance. Seed corn relatively free of these two fungi can always be selected.

On the other hand, it has been found in seed germination studies in Kansas that *Fusarium moniliforme* is present internally and externally on 94% of all the kernels of seed corn tested (8). The presence of this organism seems to be influenced but little by seasonal conditions. Species of *Rhizopus*, *Penicillium*, and *Aspergillus* occur in greater or lesser amounts and seem to fluctuate with seasonal conditions and ear worm injury (10).

In those states where satisfactory results have been reported from seed-corn treatments, the presence of *Gibberella saubinetii* and *Diplodia zeae* in the seed may be the factor of importance. The studies here reported have shown that these organisms are not common in the corn fields of Kansas (7, 10) but may occur to a very limited extent in certain areas some seasons.

EXPERIMENTAL PROCEDURE

In most instances good average seed corn was used in these experiments. The authors believe that "diseased" or inferior seed corn should never be used by the farmer even if some method of seed treatment may increase its viability. If chemical corn-seed treatments do not increase the yield when applied to the seed the farmer selects for his own planting, then the practice of seed-corn treatment is of little value in the growing of this crop.

Various sizes of plats and various procedures were followed during the different years. In all cases the experiments were replicated and all reasonable precautions were taken to reduce experimental errors.

RESULTS FOR 1927

Two sets of experiments were conducted in 1927. One consisted of comparisons of untreated seed with that treated with Improved Semesan Jr. and Bayer Dust on 20 farms in various corn growing sections of the state[4]. In all cases the farmer's own seed was used. A summary of the average field germinations and yields is given in Table 1. In these tests germination was not increased by either treatment. Yields from treated seed were slightly lower than those from controls in the case of Improved Semesan Jr., and slightly higher than those from checks in the case of Bayer Dust. The differences, however, were not statistically significant.

TABLE 1.—*Results of seed corn treatments on Kansas farms in 1927.*

Treatment	Stand* %	Yield, bu. per acre	Increase (+) or decrease (—) following seed treatment, bu. per acre
None	83	71.8	
Improved Semesan Jr., 3 trials	78	70.0	—1.8
None	83	59.2	
Bayer Dust, 17 trials	76	61.4	+2.2

*The stand counts are based upon data obtained from eight farms where both of the treatments were used in comparison with untreated check plats in the same field.

Another set of experiments was conducted the same year on the agronomy farm of the Kansas Agricultural Experiment Station. Two kinds of seed were used, *viz.*, Pride of Saline from the agronomy farm, representing clean, mature, and viable seed; and Kansas Sunflower discarded by a local seed grower because of evidence of disease, representing seed poorer than ordinarily would be considered by an average farmer. Six chemical treatments and three checks of untreated seed corn were arranged so that each treated plat would be contiguous to a check plat. Plantings of each treatment with each variety were made in five replications. The seed was planted by hand at twice the normal rate, and after counting germination, the seedlings were thinned to a uniform stand in order to differentiate between the effect of the stand factor and disease factor on yield. A summary of the results is given in Table 2.

In the case of Pride of Saline, treatments with Uspulun and copper carbonate gave the highest field germination, 88.9%, or 7.3% better than the untreated check. When calculated by Student's method, the odds in favor of a real advantage due to the treatment are Uspulun 285:1, Bayer Dust 43:1, copper carbonate 24:1, with very small differences in the case of the other treatments. The treatments were of even less benefit on the poor seed of Kansas Sunflower. In no case was a significant increase in field germination of Kansas Sunflower obtained by treatment. Kolodust gave a decrease of 9.8% under the

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[4] These tests were conducted by Professors H. H. Laude and C. E. Graves.

TABLE 2.—*Effect of seed corn treatment on stand, vigor, disease control, and yield, agronomy farm, 1927, averages of five replications.*

Treatment	Stand %	Height of plant, inches			Percentage of				Yield, bu. per acre	Increase over or decrease under check, bu. per acre
		May 28	June 7	June 29	Barren plants	Lodged plants	Diseased ears			
							By No.	By weight		
					Pride of Saline					
Uspulun	88.9	9.2	12.4	43.8	0.4	5.6	23.5	18.6	85.2	+0.6
Improved Semesan Jr.	84.5	9.0	12.8	46.5	0.4	6.0	18.1	15.1	87.2	+2.6
Bayer Dust	87.1	8.6	12.8	45.1	0.6	6.8	16.4	15.4	83.7	—0.9
Kolodust*	84.8	8.8	12.8	45.3	0.0	5.2	25.6	21.5	82.4	—2.2
CuCO$_3$†	88.9	8.8	12.4	45.4	0.2	5.4	23.1	18.1	85.9	+1.3
Creolin	85.1	8.6	12.4	43.7	0.8	7.0	21.4	18.4	86.0	+1.4
Check, no treatment	81.6	8.6	12.5	44.6	0.3	5.8	19.9	16.4	84.6	——
					Kansas Sunflower					
Uspulun	71.3	7.8	11.6	40.2	0.6	3.0	21.3	18.9	75.4	—0.6
Improved Semesan Jr.	67.5	7.6	12.0	41.1	0.2	3.6	17.2	13.8	74.9	—1.1
Bayer Dust	65.6	7.6	12.0	41.2	0.8	3.4	18.9	14.5	76.5	+0.5
Kolodust*	55.6	7.4	12.0	40.5	1.0	3.4	20.4	25.2	72.1	—3.9
CuCO$_3$†	66.2	7.8	12.0	43.0	1.0	4.0	20.3	16.3	76.5	+0.5
Creolin	60.2	7.4	11.6	39.5	0.6	3.6	20.1	16.6	74.7	—1.3
Check, no treatment	65.4	7.5	12.0	40.1	0.8	3.1	21.5	17.6	76.0	——

*Kolodust is a sulfur dust. It is not one of the advertised seed corn disinfectants, but was included in these tests.

†CuCO$_3$, which is not sold for seed corn treatment, was used in this test in comparison with more expensive seed corn disinfectants.

untreated (odds of 2499:1). The results in Table 2 show no significant advantage for either variety for any treatment in the rate of growth and vigor of the plants or in the yield and quality of the grain.

RESULTS FOR 1928

In 1928 the planting of good quality Pride of Saline seed treated with four chemical dusts was repeated. The planting was made early (April 25) to give the treated seed any advantage accruing from the lower germination temperatures usually associated with early planting. Two untreated check plats were included in each series, arranged so that each treated plat would be next to a check plat. The plantings were made in 17 replications. The results are shown in Table 3.

TABLE 3.—*Effect of seed corn treatment on stand, disease control, and yield, agronomy farm, 1928, averages of 17 replications.*

Treatment	Percentage of			Yield, bu. per acre		
	Stand	Barren plants	Lodged plants	Diseased ears	Sound ears	Total
Merko	91.1	0.7	0.7	1.9	63.8	65.7
Check, no treatment	94.5	3.3	1.5	1.9	62.7	64.6
Bayer Dust	93.6	1.2	2.7	1.5	64.1	65.6
Improved Semesan Jr.	89.9	1.9	1.9	2.2	62.7	64.9
Check, no treatment	94.3	1.5	1.5	2.3	64.2	66.5
Coppercarb*	87.6	1.5	1.5	3.1	58.9	62.0

*Coppercarb, although not sold for seed corn treatment, was used in this test in comparison with more expensive seed corn disinfectants.

In every case the average field germination of the treated seed was lower than that of the contiguous untreated check seed. The data were analyzed by Student's method and the odds that the reductions in stand were not due to chance are Merko 499 to 1, Bayer Dust 3 to 1, Improved Semesan Jr. 73 to 1, and Coppercarb 3332 to 1. No significant advantage from any treatment is apparent in the proportion of barren plants, lodged plants, diseased ears, or in total yield.

RESULTS FOR 1929

Very much the same plan of procedure as used the previous year was followed in 1929. Good quality Pride of Saline seed from the agronomy farm was used. Five seed treatments and two checks, each replicated seven times, were arranged so that each treatment except Coppercarb would be contiguous to an untreated check. A summary of the results is recorded in Table 4.

Contrary to the results of the previous year, all seed treatments showed on the average higher field germination than the untreated check plats. No consistent advantage for any of the treatments, however, was shown in proportion of erect stalks at harvest, yield of sound ears, or total yield.

TABLE 4.—*Effect of seed corn treatment on stand, disease control, and yield, agronomy farm, 1929, averages of 7 replications.*

Treatment	Percentage of		Yield, bu. per acre		
	Stand	Lodged plants	Diseased ears	Sound ears	Total
Merko	83.8	25.8	3.1	39.6	42.7
Check, no treatment	70.3	26.3	2.6	36.8	39.4
Bayer Dust	82.0	26.1	4.1	38.1	42.2
Coppercarb	81.9	28.9	2.8	36.2	39.0
Improved Semesan Jr.	76.8	22.8	3.6	39.0	42.6
Check, no treatment	75.8	25.3	3.0	40.0	43.0
Sterocide	77.8	22.9	3.9	36.4	40.3

RESULTS FOR 1930

Thus far, seed treatments consistently had shown no advantage in yield, erectness of stalks at harvest, or quality of the crop, but had shown varying responses with regard to effect on field germination. In order to test the effect of treatment on corn actually planted on farms, representative seed corn was solicited from 100 farmers in the principal corn-growing counties of Kansas early in the spring of 1930. Fifty-six samples were received from 41 counties. One hundred seeds of each sample treated with each of three disinfectants and an untreated check were planted May 12, about the average date of corn planting in this locality. Where permitted by the size of the sample, an early planting with the same treatments was made April 25. The average field germinations are shown in Table 5.

TABLE 5.—*The effect of corn seed treatments on field germination of seed from various parts of Kansas, botany field plats, 1930.*

Date planted	No. of samples	No. of counties	Laboratory germination %	Percentage of field germination			
				Sterocide	Merko	Improved Semesan Jr.	Check, no treatment
Apr. 25	20	20	88.5	84.2	83.9	87.1	83.7
May 12	56	41	84.5	81.5	82.4	83.1	81.0

There appears to be no significant difference in field germination between treated and untreated seed planted May 12. For the planting of April 25, there is a possible significant difference only in the case of Improved Semesan Jr. where the advantage due to treatment is 3.4 ±2.41%.

RESULTS FOR 1931

Seed intended for planting was again solicited from 100 farmers in 1931. Sixty-three samples from 44 counties were received. Each sample of seed was divided into five parts, of which three were treated with commercial seed corn disinfectants, namely, Improved Semesan Jr., Barbak, and Sturdidust; one was treated with Coppercarb; and one was left untreated as a check. One hundred kernels of each treatment of each of the 63 samples were planted at an early date (April 17), at a medium date (May 7–12), and, as far as the supply of seed permitted, at a late date (June 2). The data obtained are presented in Table 6.

TABLE 6.—*Effect of seed treatment of 63 samples of corn from various parts of the state on field germination and seedling vigor, botany field plats, 1931.*

Treatment	Percentage field germination*			Average height of plants, inches	
	1st planting, April 17	2nd planting, May 7–12	3rd planting, June 2	1st planting, April 17	2nd planting, May 7–12
Improved Semesan Jr.	78.0	80.7	71.6	23.5	23.5
Barbak	74.5	82.0	71.7	23.6	23.6
Sturdidust	76.4	82.0	72.0	23.9	23.6
Coppercarb	77.8	80.9	—	23.8	23.5
Check, no treatment	73.2	81.1	71.1	23.0	23.1

*Average laboratory germination of all 63 samples was 91.4%.

For percentage of field germination, the only significant difference in favor of seed treatment is shown for the early date of planting, where the greatest advantage is 4.8% for Improved Semesan Jr. Of the 63 different samples in this comparison, the treated seed showed higher germination than the check seed in 41 cases, the same germination in two cases, and lower than the check in 20 cases. The weather at Manhattan in the spring of 1931 was very unfavorable for corn germination, especially for the earlier plantings. This offered an unusual opportunity for any benefits of seed treatment to be apparent.

One of the advertised advantages of seed corn treatment is the increased vigor and more rapid growth of the seedlings. To check this point the plants of each sample for each treatment in the first two dates of planting were measured when the average size of each planting, measuring from the surface of the ground to the tip of the longest leaf, was about 2 feet. The mean measurements are shown in the last two columns of Table 6. Although there seems to be a tendency for the plants from treated seed to be slightly taller, no treatment made as much as 1 inch difference for either date of planting.

DISCUSSION

Improvement in yield and quality by economically feasible methods is the ultimate goal of changes in farming practice. On this basis the use of seed corn treatments in Kansas cannot be recommended. No treatment gave a significant increase in total yield or yield of sound corn in any year. Similarly, there is no apparent advantage from seed treatment on the basis of a decrease of barren plants or lodged plants.

Seed treatment seemed to give a rather erratic response in the different years with regard to its effect on field germination. In farm trials in 1927 germination was decreased by seed treatment, while at

Manhattan germination was decreased or slightly increased with poor seed, and was increased with good seed by seed treatment. In 1928 all seed treatments produced decreased field germination, some of the decreases being distinctly significant. In 1929 the exact reverse occurred and all treated seed germinated better than the untreated checks. In 1930 and 1931, with representative seed corn collected from farmers, there were slight average increases in field germination, particularly with Improved Semesan Jr., for the early dates of planting, but no significant difference between treated and untreated seed when planted at normal planting dates. The differences between the germination of treated and untreated seed are no greater than differences in effective field germination from year to year due to variations in seasonal conditions and are relatively unimportant as a factor affecting yield. This is particularly significant in view of the wide variation in optimum rates of planting from year to year in Kansas due to seasonal fluctuations which cannot be foretold at planting time.

Taken as a whole, these experiments indicate that on the average little advantage can be expected from treatment of seed corn with disinfectants under Kansas conditions. These results confirm those obtained in the neighboring state of Nebraska (5, 6). From the present knowledge of the control of corn diseases, the selection of well-matured, sound, bright seed ears in the field from erect plants, free from evidences of disease, and the quick and thorough drying of these ears are thought to be the most satisfactory practical seed control measures to insure full stands of strong vigorous corn plants in this region.

SUMMARY

The fungous organisms, *Gibberella saubinetii* and *Diplodia zeae*, which are recognized as fungous parasites, are less common in Kansas than *Fusarium moniliforme* and species of *Penicillium*, *Rhizopus*, and *Aspergillus*. *F. moniliforme* occurred on or inside the seed of 94% of all ears and kernels tested. Under Kansas conditions, however, this organism is not an active parasite and therefore seed corn treatments where this organism alone is involved have given no response.

Studies were conducted over a period of 5 years with seed corn from farmers and from the agronomy farm. This seed was treated with various advertised commercial disinfectants. The effect of chemical treatments of seed corn on field germination varied in different years, sometimes showing slight increases and sometimes decreases. No significant advantage in yield, quality of the crop, or proportion of lodged or barren plants was observed from the use of any of the chemical seed treatments thus far tried.

From the results of these experiments, chemical treatment of seed corn cannot be recommended as a general practice for Kansas. There may be occasional lots of Kansas-grown seed corn which will respond slightly to seed treatments in some seasons, but this would be the exception rather than the general rule.

Greater reliance should be placed in the field selection of sound, well-matured seed ears from erect stalks, to be followed by thorough and quick drying.

LITERATURE CITED

1. EDGERTON, C. W., and KIDDER, A. F. Fungous infection of seed corn kernels and the importance of germination tests. La. Agr. Exp. Sta. Bul. 193. 1925.
2. GRAVES, C. E. Corn seed treatment: Does it pay in Kansas. Kans. State Agr. Col. Ext. Serv. Ext. Circ. 72. 1928.
3. HOLBERT, J. R., and KOEHLER, B. Results of seed-treatment experiments with yellow dent corn. *U. S. D. A. Tech. Bul.* 260. 1931.
4. ————, REDDY, C. S., and KOEHLER, B. Chemical-dust seed treatments for dent corn. U. S. D. A. Circ. 34. 1928.
5. KIESSELBACH, T. A. Field experiments with seed corn treatments and crop stimulants. Nebr. Agr. Exp. Sta. Bul. 218. 1927.
6. ————. Field tests with treated seed corn. Jour. Agr. Res., 40: 169–189. 1930.
7. MELCHERS, L. E., and JOHNSTON, C. O. Corn root, stalk, and ear rot disease investigations in Kansas. (Report of Progress 1922.) Phytopath., 13: 52. 1923.
8. ————, ————. Second progress report on studies of corn seed germination and the prevalence of *Fusarium moniliforme* and *Diplodia zeae*. Phytopath., 14: 45. 1924.
9. MELHUS, I. E., REDDY, C. S., RALEIGH, W. P., and BURNETT, L. C. Seed treatment for corn diseases. Iowa Agr. Exp. Sta. Circ. 108. 1928.
10. ST. JOHN, R. R. Fungous organisms associated with Kansas seed corn. Unpublished thesis. Kans. State Col. Libr., Manhattan, Kans. 1924.
11. ZOOK, L. L., and JODON, N. E. Seed corn treatments at the North Platte Substation. Nebr. Agr. Exp. Sta. Circ. 38. 1930.

DIFFERENCES BETWEEN KOREAN AND OTHER ANNUAL LESPEDEZAS IN ROOT NODULE FORMATION[1]

J. F. DUGGAR[2]

In 1928 and 1929 examinations of roots of cultivated annual lespedezas showed that Korean plants (*L. stipulacea*) bore fewer root nodules than did common, Tennessee 76, and Kobe varieties (*L. striata*) growing in adjacent rows.[3] This difference in nodulation behavior is of peculiar interest since all of these belong to the same genus and might be expected to utilize the same kind of bacteria in the nodulation process. Hence, experiments were undertaken on Norfolk sandy loam soil at Auburn, Ala., to determine differences in nodulation among the annual lespedezas mentioned above. At frequent intervals, counts were made of nodules on the roots of large numbers of plants that had been carefully dug from several locations in each plat.

In one series of five experiments only 10% of Korean lespedeza plants had developed even one nodule per plant by the twelfth day after emergence, in contrast with 71% of nodule-bearing plants of the common lespedeza. The latter required only 13 days to reach a stage in which 85% of the seedlings bore one nodule or more against more than 52 days for Korean. common, Tennessee 76, and Kobe, all of which belong to the same species, formed root nodules at approximately the same rate.

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[1] Contribution from the Department of Special Investigations, Alabama Agricultural Experiment Station, Auburn, Ala. Received for publication July 2, 1934.

[2] Research Professor.

[3] DUGGAR, J. F. Root nodule formation on lespedeza species. Ala. Agr. Exp. Sta. Ann. Rpt., 1930:37; 1931:54–55.

In another test, plants about 6 weeks old averaged 3.50 nodules per plant on common, 5.00 on Tennessee 76, and 6.75 on Kobe against only 1.48 on Korean. In still another experiment plants of about the age mentioned above bore an average of only 0.97 nodule per plant in contrast with 9.50 nodules per plant of common lespedeza.

April plantings were made in 1931 and 1932, and for these two years the average numbers of nodules per plant at successive ages are shown in Table 1.

TABLE 1.—*Differences among varieties of annual lespedeza in forming root nodules without inoculation or fertilization on Norfolk soils, averages for 1931 and 1932.*

Variety	Average number of nodules per plant at age of				
	18–22 days	27–31 days	43–44 days	66–71 days	91–107 days
Common.....	2.05	2.37	2.52	4.45	11.62
Tennessee 76..	2.27	1.93	3.07	5.51	23.23
Kobe.........	2.18	3.48	3.55	5.43	16.00
Korean.......	0.14	0.19	0.67	0.67	2.36

The data summarized in Table 1 and in the preceding paragraphs show that under conditions of these experiments Korean lespedeza plants growing in Norfolk soils without artificial inoculation bore invariably only a very small number of root nodules per plant. Korean plants, as shown in Table 1, had fewer nodules at each count than either of the other three varieties. When planted early, common, Tennessee 76, and Kobe lespedezas always developed an abundant supply of root nodules spontaneously and promptly.

Similar experiments were also conducted for a single year on four soils of the Cecil series. Although on two of these there was general agreement with the results on Norfolk soils, yet on the other two fields, Korean plants by harvest time had attained equality in nodule numbers with the other annual lespedezas.

The effects of artificial inoculation of seed with cultures prepared from Korean nodules were repeatedly tested. The data for seven comparisons in which inoculated and non-inoculated Korean seed were planted at late dates in 1930, 1931, and 1932 showed that at every date of examination plants from inoculated seed bore larger numbers of nodules than did non-inoculated plants. Likewise, from April planting in 1933 Korean plants attained by late summer an average of 10 nodules for each as compared with an average of only 2 nodules for the plants not artificially inoculated.

The failure of Korean plants to develop nodules promptly and abundantly on soil where the other three annual varieties of the same genus, but of a different species, became promptly and intensively nodulated, presents an interesting anomaly.

SUMMARY

Korean lespedeza plants (*L. stipulacea*) growing on Norfolk soils developed significantly fewer nodules per plant than did common, Tennessee 76, and Kobe varieties, all of which formed nodules

promptly and abundantly. This held true at every date of examination throughout each of 5 years.

Inoculation of the seed of Korean lespedeza in eight experiments invariably resulted in rather small but consistent increases in the number of nodules over those on the non-inoculated plants of this species.

Korean lespedeza here afforded an exceptional case, in that differences between species within the same genus interposed impediments to ready cross-inoculation.

ROOT NODULE FORMATION AS AFFECTED BY PLANTING OF SHELLED OR UNSHELLED SEEDS OF BUR CLOVERS, BLACK MEDIC, HUBAM, AND CRIMSON AND SUBTERRANEAN CLOVERS[1]

J. F. DUGGAR[2]

The purpose of these experiments was to learn whether artificial inoculation might have more prompt or intense effects when the inoculum was applied to the relatively bulky pods of the unshelled seeds than to the smaller and smoother surfaces of the shelled seeds. The experiments were made on fields of the Experiment Station Farm and of other farms near Auburn in 1926, 1928, 1930, and 1933. The sandy soils utilized were in the Norfolk series and showed acid reactions. Except as noted for one garden soil, these soils lacked the appropriate strain of nitrogen-fixing bacteria.

The planting dates were usually late, or after the soil temperatures had fallen considerably below those prevailing at the optimum time for planting seed of such legumes. To avoid the usual slower germination of the bur clovers when planted in the bur, the unshelled seeds of all bur clovers were briefly scalded in water, near the boiling point, after which the inoculum was applied. The seed were inoculated by separately soaking both the shelled and unshelled (pod inclosed) seed in a suspension of appropriate cultures.

This study was limited, in most of these experiments, to such effects as might be manifested by the seedlings in their earlier stages of growth through possible differentiation in the formation of root nodules.

During the early life of the seedlings, frequent examinations were made to determine the percentage of plants bearing nodules, and in certain experiments, to ascertain the average number of nodules per plant. The age of the seedlings at each date of examination was reckoned from the date of emergence.

The study included two species of bur clover (*Medicago arabica* and *M. rigidula*), black medic (*M. lupulina*), hubam (*Melilotus alba annua*), crimson clover (*Trifolium incarnatum*), and subterranean clover (*T. subterraneum*).

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[2] Research Professor.

RESULTS

Table 1 summarizes the detailed data for the numerous plantings by averaging the percentage of nodule-bearing plants as found at the indicated ages of the seedlings. Hence, the figures are necessarily unweighted averages, which in this case constitute close approximations to mathematical accuracy.

TABLE 1.—*Percentages of nodule-bearing plants of certain winter legumes from shelled and unshelled seed which were inoculated.*

Plant	Condition of seed	Average number days after emergence until		Average percentage nodule-bearing plants at	
		Early examination	Later examination	Early examination	Later examination
		On Non-inoculated Soil			
Bur clover, spotted leaf; average 2 plantings	Shelled	12	23	19	20
	Unshelled	12	23	50	100
Bur clover, early spotted leaf; average 5 plantings	Shelled	23	37	18	27
	Unshelled	23	36	86	96
Bur clover, Tifton; average 3 plantings	Shelled	22	41	0	11
	Unshelled	22	39	33	87
Black medic; average 2 plantings	Shelled	17	21	15	38
	Unshelled	19	26	34	73
Hubam; average 3 plantings	Shelled	30	44	32	46
	Unshelled	32	46	75	92
Crimson clover; average 5 plantings	Shelled	19	27	50	54
	Unshelled	18	26	61	97
Subterranean clover; average 5 plantings	Shelled	18	22	41	49
	Unshelled	18	21	52	73
		On Inoculated Soil			
Bur clovers; average of 3 late plantings	Shelled	19	33	21	57
	Unshelled	19	33	18	59

The tendencies indicated by the data in Table 1 and in the detailed tabulation upon which it is based may be summarized as follows for the several winter legumes when grown on soil requiring artificial inoculation of seed:

1. The planting of inoculated, unshelled seed of all three kinds of bur clover was followed by earlier nodulation and by a much larger percentage of nodule-bearing young seedlings than when shelled inoculated seed was planted.

2. The advantage from the use of unshelled seed of black medic, hubam, and crimson and subterranean clovers was somewhat less marked and uniform than in the case of the bur clovers.

3. On garden soil, abundantly supplied with the appropriate strain of legume bacteria by preceding crops of bur clover, the planting of unshelled seed of three bur clovers without artificial inoculation was

followed by no superiority in the nodulation of the resulting young seedlings over those from shelled non-inoculated seed.

The measurement of nodulation by the percentage of tubercle-bearing plants during the early life of the seedlings points out no differences that may exist subsequent to the time when nearly every seedling from both shelled and unshelled seed bears at least one nodule.

To measure differences in nodulation subsequent to this stage, the plan was extended to include, especially in the experiments of later years, a record of the number of nodules found. Table 2 shows for the winter legumes indicated the average number of nodules per plant at successive ages of the seedlings.

TABLE 2.—*Average number of nodules per plant of certain winter legumes following planting of shelled and unshelled, inoculated seed on non-inoculated soil.*

Plant	Condition of seed	Date of emergence	Days after emergence to successive examinations	Average number nodules per plant at successive ages
Early spotted leaf bur clover	Shelled	Feb. 25, '30	41, 53	1.60, 1.55
	Unshelled	Feb. 27, '30	41, 50	5.42, 5.00
Black medic	Shelled	Feb. 24, '30	21, 28, 42, 49	0.06, 0.00, 2.27, 4.25
	Unshelled	Feb. 26, '30	19, 26, 42, 47	0.11, 0.24, 2.46, 2.20
Hubam	Shelled	Oct. 9, '30	44, 65, 75, 101	0.00, 0.87, 0.27, 0.24
	Unshelled	Oct. 10, '30	43, 64, 74, 100	2.05, 2.00, 3.80, 4.20
Hubam	Shelled	Nov. 9, '30	12, 19, 27, 52	0.50, 0.36, 2.00, 2.50
	Unshelled	Nov. 12, '30	9, 16, 24, 49	1.54, 1.14, 2.00, 3.27
Hubam	Shelled	Nov. 28, '33	34, 49, 70, 133	1.07, 2.80, 10.08, 29.55
	Unshelled	Nov. 20, '33	42, 57, 78, 141	2.91, 3.52, 10.15, 24.00
Crimson clover	Shelled	Feb. 24, '30	21	1.80
	Unshelled	Feb. 26, '30	19	1.60
Crimson clover	Shelled	Oct. 9, '30	18, 23, 27	0.67, 0.44, 0.46
	Unshelled	Oct. 10, '30	18, 22, 26	0.00, 0.19, 0.75
Crimson clover	Shelled	Nov. 13, '33	30, 50, 65, 86, 149	1.52, 5.67, 7.64, 13.46, 42.15
	Unshelled	Nov. 14, '33	29, 49, 64, 85, 148	3.86, 11.03, 11.73, 21.41, 45.20

Intensity of nodulation between young plants from shelled and from unshelled seed differed with the species, that is, with the kind of pod that covered the artificially inoculated seed as summarized below:

1. Plants from unhulled seeds of early spotted leaf bur clover developed significantly larger numbers of nodules than did those from shelled seeds. This is in general accord with results from all three kinds of bur clover as measured by percentages of nodule-bearing plants.
2. Black medic in its early stages of growth showed in a single February planting no marked differences in intensity of nodulation between plants from shelled and unshelled seeds.
3. With crimson clover there was in one season a decided intensification in the nodulation of young plants from unshelled seed, but in two other seasons there was practical equality in nodule numbers following the planting of shelled and unshelled seed.
4. In all three fall plantings of hubam the use of unshelled seed was followed by notably increased nodulation of the young seedlings.
5. Generally, any initial advantage in nodulation from the use of unshelled seed tended to disappear as the plants aged.

DISCUSSION

The more prompt and more intensive nodule formation that occurred from the inoculation of unshelled as compared with shelled seed of certain species is interpreted as probably due to the greater bulk and rougher surface of the unshelled seeds. It appears reasonable that the larger and rougher the absorbing surface, the greater the amount of suspended inoculum conveyed to the seedbed by the artificially inoculated seed. The seed burs of all the bur clovers, consisting of loosely twisted, spiral pods, afford an especially large and retentive surface to which doubtless a materially larger number of microorganisms adhere than to the smaller smooth surfaces of the shelled seed.

This superiority of unshelled seed as regards initial nodulation of the seedlings has been especially marked with all the bur clovers. This advantage of unshelled seed has been less uniform with black medic, which has smaller and closer-lying seed coverings, and also less uniform with crimson and subterranean clovers.

SUMMARY

Artificially inoculated seeds, both shelled and unshelled, of three bur clovers, black medic, hubam, crimson clover, and subterranean clover were planted in field experiments on Norfolk soils that lacked the appropriate nitrogen-fixing micro-organisms. At successive ages of the young seedlings, examinations of roots were made to determine percentages of nodule-bearing plants or average number of root tubercles per plant.

Nodule formation was more prompt and generally more intensive, at least during the early seedling stage, following the use of unshelled seed of the bur clovers and hubam, and in some of the plantings of crimson and subterranean clovers.

The superiority in promptness of nodulation from planting unshelled seed was attributed to the conveyance of larger amounts of inoculum on the more bulky and rougher surfaces of the unshelled seeds than on the smaller and smoother surfaces of shelled seeds.

No advantage in initial nodulation from the use of unshelled seed was found where three bur clovers were planted without artificial inoculation in a soil amply supplied with the symbiotic micro-organisms appropriate to these legumes.

COLD RESISTANCE OF THREE SPECIES OF LESPEDEZA COMPARED TO THAT OF ALFALFA, RED CLOVER, AND CROWN VETCH[1]

H. M. Tysdal and A. J. Pieters[2]

Lespedeza species, including both the annual and perennial, have come into unusual prominence during the past few years. With increasing interest in the crop, information as to the cold resistance of the different species has been demanded. Reports were received in March, 1932, of late freezes after most of the lespedeza seedlings had appeared in the field which were very destructive to the stands, in some places complete. Here and there, however, claims were made that one lespedeza or another endured a temperature as low as 16° F.

In order to obtain more precise data on the minimum lethal temperature of various lespedezas and the influence of age on cold resistance, controlled freezing tests were undertaken through the use of the facilities of the Plant Pathology Department, Nebraska Agricultural Experiment Station.

MATERIAL AND METHODS

The results herein reported cover 2 years' work. The first year six lespedezas were used, including three of common lespedeza (*L. striata*), two of Korean lespedeza (*L. stipulacea*), and the perennial lespedeza (*L. sericea*), together with Turkistan alfalfa and red clover. The second year the same three species were included, but different seed was used, and crown vetch (*Coronilla varia*) was added.

Plantings were made in rows in flats 15 x 18 inches so that all lots tested were included in each flat. The planting order was arranged so each lot occurred at the edge of the flat an equal number of times.

Since it was desired to determine the influence of stage of development on resistance to cold, seed was sown at intervals of from a week to 10 days. The groups which were to be hardened were sown 6 to 10 days earlier to take care of lack of growth during hardening. The so-called hardened groups were kept in the hardening room at an average of 2° C for from 5 to 8 days.[3]

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[2] Associate Agronomist and Principal Agronomist, in charge, respectively.

[3] For a description of the equipment used see Peltier, G. L. Control equipment for the study of hardiness in crop plants. Jour. Agr. Res., 43: 177–182. 1931.

TABLE 1.—*Percentage survival of alfalfa, red clover, and lespedezas of different ages after exposure for 16 hours to various temperatures.*

Age* when frozen, days	Freezing termperature, °C	Alfalfa %	Red clover %	*L. sericea*, No. 04730 %	Common lespedeza, No. 19956 %	Tennessee 76, No. 19955 %	Kobe No. 81742 %	Korean extra early No. 59379 %	Korean, No. 82436 %
				Hardened 6–10 Days at 0°–2° C					
42, 49	—4.1°	100	100	15	0	0	0	0	0
	—2.8°	100	100	73	0	0	4	0	0
	—2.5°	100	100	84	95	48	36	59	25
	—1.7°	100	100	100	92	89	100	82	67
Average		100	100	68	47	34	35	35	23
23, 35	—4.1°	100	100	17	4	0	0	0	0
	—2.8°	100	100	62	26	11	9	7	0
	—2.5°	100	100	94	51	43	34	35	23
	—1.7°	100	100	71	14	32	95	20	35
Average		100	100	61	24	22	35	16	15
9, 14	—4.1°	100	100	97	99	100	96	30	39
	—2.8°	100	100	94	100	100	89	17	3
	—2.5°	100	100	100	100	100	99	81	82
	—1.7°	100	100	100	100	100	100	91	80
Average		100	100	98	100	100	96	55	51
Total average		100	100	76	57	52	55	35	30

Not Hardened

42, 49	—4.1°	100	100	46	2	2	0	0	0
	—2.8°	100	100	100	100	93	88	96	78
	—2.5°	100	100	91	81	89	96	84	61
	—1.7°	100	100	100	100	100	100	100	100
Average		100	100	84	71	71	71	70	60
23, 35	—4.1°	100	100	23	0	5	9	2	9
	—2.8°	100	100	0	4	0	18	8	9
	—2.5°	100	100	85	83	85	79	73	48
	—1.7°	100	100	91	100	100	100	79	92
Average		100	100	50	47	48	52	41	40
9, 14	—4.1°	39	30	94	100	99	80	7	27
	—2.8°	78	88	94	97	93	76	43	66
	—2.5°	94	97	98	100	100	97	81	75
	—1.7°	100	100	100	100	100	100	96	99
Average		78	79	97	99	98	88	57	67
Total average		93	93	77	72	72	70	56	56

*First figure is age of unhardened material, second figure age of hardened material at time of freezing.

LENGTH OF FREEZING EXPOSURE AND SOIL TEMPERATURE

To determine the approximate freezing exposure, preliminary freezing tests were made on two boxes of plants, one from the warm greenhouse and one from the hardening room, exposed 5 hours at —5.8° C. As an average of all six lespedezas, the box from the warm greenhouse had a 90% survival while the box from the hardening room with cold soil had a 10% survival. The soil temperature a half inch below the surface in the box from the warm greenhouse at the end of the freezing was 3.7° whereas that from the hardening room was 0°. This test emphasized the necessity of comparable soil temperatures, and when an additional test with two boxes frozen 16 hours showed little difference in minimum soil temperatures, this period was adopted throughout the 1933 experiments. In 1934, when the comparison between hardened and non-hardened material was not of prime interest, an 8-hour length of exposure was used.

Survival counts were made approximately 10 days after freezing. Several times counts were made the next day after freezing and it was interesting to note that in most cases a very accurate count on survival of the common and Korean lespedeza could be made at this time. If the tops were injured, the plant was killed. This was not true, however, of *L. sericea*, red clover, or alfalfa, which possess the ability of starting new growth from the crown.

EXPERIMENTAL RESULTS

From Tables 1 and 2, in which the results of both the 1933 and 1934 tests are given, the following conclusions may be drawn.

Relative cold resistance of species.—As would be expected, both alfalfa and red clover are much more cold resistant than any of the lespedeza species. There appears only one exception to this general rule, that being in the very young stage of the unhardened material. This presents an interesting reversal which will be later considered in more detail. The perennial lespedeza, *L. sericea*, is distinctly more cold resistant than the common or Korean lespedeza, particularly in the hardened condition, but this is also true in the non-hardened condition. The common lespedezas, represented by common Nos. 19956, 22123, Tennessee No. 76, and Kobe, are all superior in cold resistance to the Korean or Early Korean. Both of the latter were consistently lowest of the lots tested at all stages of growth.

Crown vetch had more cold resistance than any of the lespedezas but somewhat less than alfalfa or red clover.

Influence of stage of development on resistance to cold.—Careful record was made of the height of growth and number of leaves of the plants the survival of which is reported in Table 1. Some variation in growth and number of leaves occurred between the different species, but the differences were not great and for brevity only an average is here reported. For plants 42 days old, in which practically no growth occurred in the hardening room, the average height was 1½ to 2 inches and they had five to seven trifoliolate leaves. Plants 23 days old averaged 1 to 1½ inches high and had one to three trifoliolate leaves. Plants 9 days old averaged about ½ inch high and had only the cotyledons expanded. In most cases the third leaf was not showing. In all instances red clover and alfalfa were highest when measured.

As can be noted from Table 1, the plants of various stages of growth were exposed to the same temperatures. This is also true of those reported in Table 2. It is very interesting to note that, in general, alfalfa and red clover increase in hardiness with increasing age, while the lespedezas decrease in hardiness with advancing age. This can be seen from the unhardened material, as in the hardened material, temperatures severe enough to kill alfalfa or red clover were not used.

TABLE 2.—*Comparative cold resistance of unhardened alfalfa, red clover, crown vetch, and lespedeza at various ages reported in percentage survival after exposure to temperatures from —4.7° to —7.4° C for 8 hours.*

Age when frozen, weeks	Grimm alfalfa	Red clover No. 18789	Crown vetch No. 19295	*L. sericea* No. 17291	Common lespedeza No. 22123	Korean lespedeza No. 22117
2..........	77	69	73	76	72	66
3..........	94	74	79	60	56	47
4..........	99	95	82	44	38	34
5..........	99	95	76	54	45	30
6..........	100	97	63	41	17	22
7..........	100	98	68	36	34	10
8..........	100	100	83	47	34	13
Average	96	90	75	51	42	32

The lespedezas were distinctly superior to red clover or alfalfa in the unhardened cotyledonous stage, whereas in the hardened cotyledonous stage the reverse was true. Among the lespedezas the highest percentage survival without exception occurred at the youngest stage.

To inquire further into the reaction of alfalfa as compared to lespedeza at a very early stage, seeds of Grimm alfalfa and Korean lespedeza were soaked in water from 1 to 5 days then laid out on blotting paper and frozen in the freezing chamber. The seeds were then immediately planted in boxes and the number of plants produced determined. The results are reported in Table 3.

TABLE 3.—*Effect of freezing on alfalfa and on lespedeza at very early stages.*

Number days soaked	Percentage germination after exposing 1 hour to indicated temperature			
	—5°C		—20°C	
	Korean lespedeza	Grimm alfalfa	Korean lespedeza	Grimm alfalfa
0	90	90	92	90
1	92	34	78	0
2	88	36	18	0
3	66	24	4	0
5	46	14	0	0

The Korean lespedeza was frozen with the hulls on, but experiments with dehulled seed showed that, although the hull served to protect the seed somewhat, the lespedeza was still far superior to the alfalfa. In the above experiment a temperature of —5° was sufficient to injure the alfalfa severely, while the lespedeza was injured very little except where the seed was soaked 5 days. The —20° killed all the alfalfa, but many Korean lespedeza seeds produced plants.

Lethal freezing temperatures of lespedezas.—Many factors, no doubt, influence the precise minimum temperatures plants will endure. Among others are the condition of the plant, condition of the soil, and length of exposure to the low temperatures. Particularly important is the condition of the plant, involving as it does the stage of growth, previous treatment, and environment. The amount of hardening is also an important consideration in those species which respond to hardening, but probably is not of so much importance in the annual lespedezas which respond very little, if at all, to hardening. From Table 1 it can be observed that under the conditions of this experiment an average temperature of —4.1° C for 16 hours almost completely killed all the lespedezas, except those in the cotyledonous stage. Temperatures recorded automatically every 16 minutes showed that the minimum temperature during the entire period was —5° C. The exposure with an average temperature of —2.8° and a minimum of —4.5° showed considerable killing of common and Korean lespedeza and in one instance of *L. sericea*. The —2.5° exposure with a minimum of —4° caused relatively little killing.

The 1933 freezings, with only 8 hours exposure in the freezing chamber, required somewhat lower temperatures to cause killing. An average temperature of —5.7° C for 8 hours caused almost complete killing of the lespedezas, whereas a temperature of —4.6° for the same length of time resulted in a relatively high survival.

SUMMARY

Controlled freezing tests are reported for common lespedeza (*L. striata*), Korean lespedeza (*L. stipulacea*), perennial lespedeza (*L. sericea*), and crown vetch (*C. varia*). Alfalfa and red clover were included for comparison.

Korean lespedeza proved to be least cold resistant of the group tested, the common lespedezas next, and perennial lespedeza most cold resistant. Crown vetch had more cold resistance than any of the lespedezas, but somewhat less than alfalfa or red clover.

With reference to the influence of stage of growth on cold resistance in general, alfalfa and red clover increased in cold resistance with advance in stage of growth after the two-leaf stage, while lespedezas decreased in cold resistance, a rather striking reversal being shown in this respect. When seeds of Korean lespedeza and Grimm alfalfa were soaked from 1 to 5 days, the Korean seed was in every instance more cold resistant than the Grimm alfalfa.

The minimum temperature to which lespedezas may be subjected without killing no doubt varies under different conditions. In these experiments an average temperature of —4.1° C (22.8° F) for 16 hours proved lethal to all lespedezas. A minimum temperature of —4.5° with an average of —2.8° showed considerable killing of Korean and common lespedezas.

SOIL FACTORS WHICH PREVENT TOXICITY OF CALCIUM CYANAMIDE[1]

D. S. FINK[2]

The form in which the nitrogen in commercial Cyanamid[3] exists is crystalline calcium cyanamide, $CaCN_2$. This compound is not stable in aqueous solution, but, according to Akhromeiko (1),[4] hydrolizes immediately to give calcium acid cyanamide and calcium hydroxide in accordance with the following reaction:

$$\text{(a)}\ 2(CaCN_2) + 2H_2O = Ca(HCN_2)_2 + Ca(OH)_2$$

Ulpiani (19) shows that calcium acid cyanamide is further hydrolyzed to give urea and calcium hydroxide as follows:

$$\text{(b)}\ Ca(HCN_2)_2 + 4H_2O = 2\ NH_2CONH_2 + Ca(OH)_2$$

This reaction is catalyzed by acids, strong alkalies, inorganic salts, and particularly by the oxides of iron and manganese as shown by a number of investigators (13, 9, 8, 5).

Crowther and Richardson (6) and Davis (7) show that normal agricultural soils are seldom likely to be devoid of the necessary catalyst. The base-absorbing complex of the soil may speed up the disappearance of cyanamide from the soil solution through the removal of calcium and the liberation of free cyanamide, H_2CN_2, which is rapidly hydrolyzed to urea (6).

Kappen (10) and Pranke (18) give data to show that the reactions preceding the formation of urea are of a physico-chemical nature. The subsequent changes are all biological. That cyanamide is rapidly transformed to urea in the soil is shown by Couchet (4). It is well known that urea is ammonified extremely rapidly in normal soils, and urea produced from Cyanamid behaves as urea added directly (6).

When Cyanamid is used as a source of nitrogen, care must be taken to allow sufficient time for the complete removal of the CN_2 anion from the soil solution before any seeding is done. The manufacturers warn that if this precaution is not taken severe injury to germination may result, and their general recommendation is to delay planting 3 days for each 100 pounds of Cyanamid applied per acre.

Crowther and Richardson (6) have shown that the toxicity of Cyanamid to germinating seeds is due to cyanamide itself. It has long been known, however, that in many normal agricultural soils the disappearance of cyanamide from the soil solution is rapid and complete within a few days. It has been shown more recently by Kubiena (11) and by Meyer and Obst (14) that in sandy soils and in some of the heavier soil types which are acid, cyanamide disappears slowly and the injurious effects on the crop may be quite marked.

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[2] Formerly, Fellow, University of Wisconsin; now Research Assistant, Department of Agronomy, Maine Agricultural Experiment Station, Orono, Me. The writer wishes to express his appreciation for the helpful suggestions and criticisms tendered by Professor E. Truog.

[3] The term Cyanamid, final "e" omitted, refers to the commercial product.

[4] Figures in parenthesis refer to "Literature Cited," p. 939.

The purpose of this investigation was to determine what soil factors are responsible for the immediate and complete removal of cyanamide from the soil solution in the case of normal agricultural soils. It was thought that such data may give some indication as to what might be added to the fertilizer material itself to hasten the removal of cyanamide from the soil solution and also make possible more intelligent predictions as regards the deportment of Cyanamid in various kinds of soils, and hence better practices in its use.

GENERAL PROCEDURE OF INVESTIGATION

The general procedure with soils was to mix thoroughly 10 milligrams of nitrogen in the form of fresh powdered Cyanamid with 100 grams of soil and moisten with water equivalent to 40% of its pore space. After definite intervals of time, each lot of soil was analyzed for cyanamide nitrogen remaining in solution by adding sufficient water to make in all 100 cc, shaking thoroughly, allowing to stand 30 minutes to insure equilibrium, and then filtering through a Gooch crucible having an asbestos pad. A 20-cc aliquot of the filtrate was treated with 2 cc of 7.5 normal ammonium hydroxide and the cyanamide precipitated with a slight excess of 0.1 molar $AgNO_3$. After standing several hours, the precipitate was collected in a Gooch crucible using a pad made from filter paper pulp. It was washed eight times with water and the cyanamide nitrogen determined by the regular Kjeldahl method with the important modification suggested by Crowther and Richardson (6) of using dilute sulfuric acid to insure complete hydrolysis of the cyanamide.

When testing various substances common to soils for their effect on cyanamide, the procedure was to treat 100 grams of quartz sand, which alone had practically no effect on the disappearance of cyanamide, with 10 milligrams of Cyanamid nitrogen, and definite amounts of these materials. These mixtures were moistened with sufficient water to produce a crumbly state, and after standing for varying intervals of time were analyzed for cyanamide nitrogen the same as for soil. If colloidal organic materials were used, and in some cases with soils high in organic matter, it was necessary at the time of precipitating the silver cyanamide to add 2 cc of 5% calcium nitrate solution to effect coagulation of the precipitate.

INFLUENCE OF SOIL REACTION

To study the effect of soil reaction on the disappearance of cyanamide from the soil solution, four different silt loams were used, *viz.*, Marshall, Knox, Carrington, and Miami. These soils were originally strongly acid and portions of each were limed 2 years ago to bring them up to approximately pH 6.5 and pH 7.0, respectively. The data in Table 1 show clearly that the disappearance of cyanamide from the soil solution is somewhat more rapid for each soil type at the lowest pH value.

Pranke (18) and others state that the rapid, immediate disappearance of cyanamide from the soil solution corresponds to an initial period of adsorption. If this is true, then the data of Table 1 indicate that for a given soil type the adsorption is more rapid for the most acid soil. However, reference to Colby silt loam, Table 1, shows that it removes cyanamide from solution very slowly in comparison to the strongly acid Miami and Carrington silt loams in spite of the fact that it is decidedly more acid than these two soils. It appears that reaction plays only a minor part in the removal of cyanamide from solution.

TABLE 1.—*Influence of soil type on the disappearance of cyanamide from solution, 10 mgm of Cyanamid nitrogen originally added.*

Soil type	pH of soil	Milligrams cyanamide nitrogen in soil solution after		
		24 hours	48 hours	72 hours
Marshall silt loam	7.0	4.285	2.150	1.430
Marshall silt loam	6.3	3.855	1.840	0.855
Marshall silt loam	5.0	3.285	1.425	Trace
Knox silt loam	7.2	5.000	3.570	1.570
Knox silt loam	6.7	4.285	2.570	1.140
Knox silt loam	5.4	3.855	1.570	Trace
Carrington silt loam	7.0	4.855	2.570	Trace
Carrington silt loam	6.3	4.140	2.000	Trace
Carrington silt loam	5.2	3.140	1.425	0.000
Miami silt loam	7.0	4.285	2.720	1.000
Miami silt loam	6.6	3.140	1.700	Trace
Miami silt loam	5.5	2.570	1.150	0.000
Plainfield sand	5.6	9.500	9.170	8.700
Colby silt loam	4.7	7.700	5.550	3.970
Hawaiian laterite	6.0	2.050	Trace	None

INFLUENCE OF FREE IRON OXIDE

To study the effect of the free iron oxide content of soils on the disappearance of cyanamide, the following soils were used which are low in organic matter:

	Free iron oxide content	pH
Plainfield sand	Low	5.6
Colby silt loam	Medium	4.7
Hawaiian laterite	High	6.0

The curves in Fig. 1 show clearly that the disappearance of cyanamide from the soil solution is decidedly more rapid in soils with a high amount of free iron oxide. This would be expected in view of the work of several investigators previously mentioned (13, 9, 8, 5) who have shown that pure oxides of many inorganic elements have the power to adsorb and decompose cyanamide, and that iron oxide is particularly active in this respect.

INFLUENCE OF ORGANIC AND INORGANIC BASE EXCHANGE MATERIAL

Crowther and Richardson (6) express the opinion that the base-absorbing complex of the soil plays an important part in bringing about the disappearance of cyanamide from the soil solution. This contention, however, is not supported by the curves in Fig. 1. The base exchange capacity of Colby silt loam is approximately 20 milli-equivalents per 100 grams of soil, which is similar to that of Carrington silt loam and somewhat higher than that of Miami silt loam. It should be pointed out that the high base exchange capacity of Colby

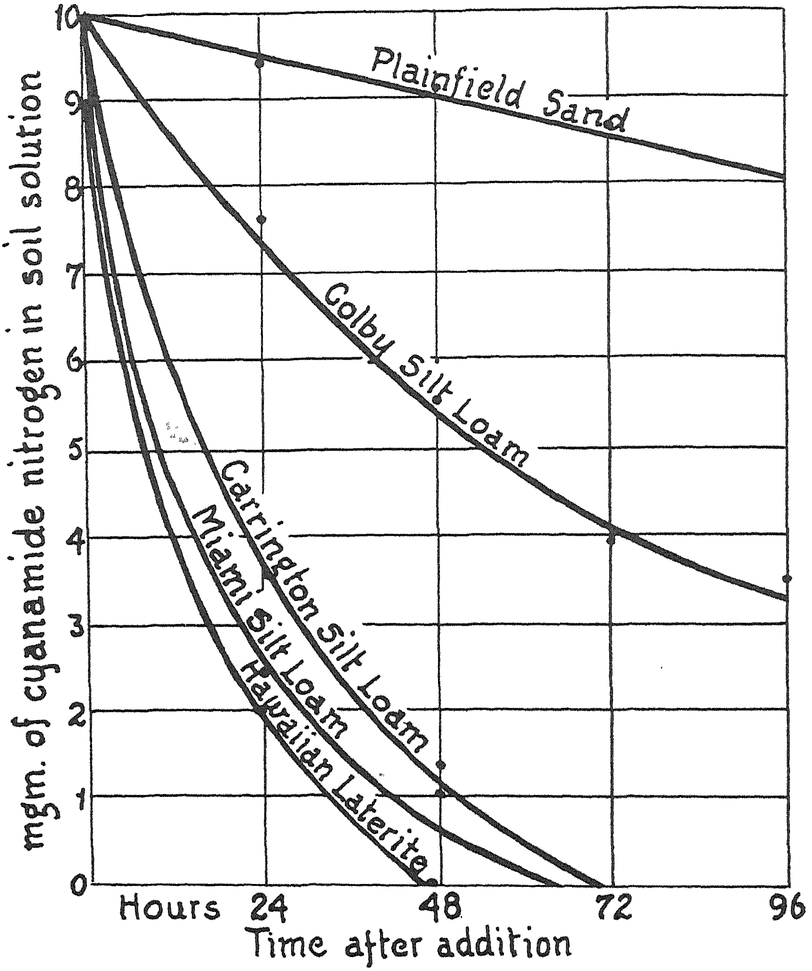

FIG. 1.—Influence of soil type on the rate of disappearance of cyanamide from solution. Ten milligrams of cyanamide nitrogen originally added.

soil is due almost entirely to inorganic base exchange material, whereas in the case of the Miami and Carrington soils organic base exchange material is abundant. Further evidence will be given to the effect that the exchange property of materials plays no part in the removal of cyanamide from solution, except that it may function in buffering the reaction in the vicinity of a Cyanamid particle thus preventing the formation of dicyandiamide which takes place at about pH 7.0 (3).

One of the main differences of the Colby soil in contrast to the Miami and Carrington soils is that of the organic matter content. That the organic matter content of a soil plays an important part in the disappearance of cyanamide from solution was shown by various investigators (11, 17). These investigators, however, relate the action of the organic matter in the decomposition of Cyanamid to an appropriate biological flora. The following experiment was conducted to determine exactly what part organic matter plays from a physico-chemical standpoint, particularly organic matter possessing base exchange properties. Also included in this study was an investigation to determine what effect, if any, pure inorganic base exchange material has on the removal of cyanamide from solution.

For this purpose two peats possessing base exchange properties were used. One peat was obtained from Michigan and will be referred to as peat No. 1. It has a base exchange capacity of 285 milli-equivalents per 100 grams. The other peat came from Coddington, Wisconsin, and will be referred to as peat No. 2. It has a base exchange capacity of 35 milli-equivalents per 100 grams.

These peats were calcium saturated by soaking 200 grams in neutral calcium acetate for 48 hours, leaching further with 2.5 liters of neutral calcium acetate, and finally washing free of calcium with water. They were hydrogen saturated by leaching with 0.05 N HCl until free of calcium and finally washed free of chlorides. The calcium-saturated peat had a pH of 7.0 and the hydrogen-saturated of 4.0.

Inorganic hydrogen saturated base exchange material was prepared from bentonite by leaching with normal ammonium nitrate solution acidified to 0.05 normal acidity with nitric acid, until free of calcium, and finally washing with 85% by volume of alcohol to remove soluble salts. The material was first air dried and then placed in a furnace at 450° C until it was free of ammonia. The final product had a pH value of 4.0.

One hundred gram mixtures of quartz sand containing 7.4% base exchange materials were made. Each 100-gram mixture was treated with 10 milligrams of Cyanamid nitrogen and sufficient water to maintain a crumbly state. The results are shown in Table 2.

Fig. 2 shows the effect of these variously saturated base exchange materials on the disappearance of cyanamide. It is obvious in the case of organic base exchange material that the state of saturation with respect to calcium or hydrogen is not the controlling factor. The slightly more rapid disappearance of cyanamide in the case of the hydrogen-saturated peat over the calcium-saturated peat is not sufficient to conclude that the removal of calcium is a necessary step in the transformation of cyanamide to urea. For, if it were a question of the removal of calcium from the calcium acid cyanamide molecule, thus speeding up the reaction in the direction of the formation of urea (equation b, page 929), the hydrogen-saturated peat should be decidedly more active than the calcium-saturated. It will be shown later that other materials possessing no base exchange capacity have the power to remove cyanamide from solution very rapidly.

TABLE 2.—*Influence of materials indicated on disappearance of cyanamide from solution when added (7.4%) to quartz sand treated with 10 milligrams of cyanamide nitrogen.*

Base exchange material added	Milligrams cyanamide nitrogen remaining in solution after			
	24 hours	48 hours	72 hours	96 hours
Bentonite, H-saturated	9.95	9.63	9.45	8.75
Peat No. 2, Ca-saturated	8.50	7.52	6.30	5.72
Peat No. 2, H-saturated	7.55	5.80	3.55	2.05
Peat No. 1, Ca-saturated	5.62	3.87	0.97	None
Peat No. 1, H-saturated	4.48	2.75	Trace	None
Activated charcoal	2.50	Trace	None	None
Activated charcoal containing 11% iron oxide	None	None	None	None

The curves in Fig. 2 show also that peat No. 1 is considerably more active than peat No. 2. This happens to correlate with the base exchange capacity for the two peats, peat No. 1 having a base capacity several times greater than peat No. 2. This variation in the capacity of organic matter to adsorb cyanamide from solution suggests an explanation for the contradictory results reported by various investigators on the disappearance of cyanamide in soils with high organic matter content (5, 6).

The disappearance of cyanamide from solution in the case of the mixture containing 7.4% hydrogen-saturated peat No. 1 (Fig. 2) takes place at about the same rate as in normal agricultural soils (Table 1). These normal agricultural soils contain from 5 to 8% organic matter, and this close correlation indicates that organic matter is chiefly responsible for the removal of cyanamide from the soil solution.

Inorganic hydrogen saturated base exchange material prepared from bentonite is very inactive, as shown in Fig. 2. Other inorganic materials, including an artificial zeolite, Doucil, possessing base exchange properties, were tried and found to be inactive.

While it has been shown that organic matter is chiefly responsible for the removal of cyanamide from the soil solution, nevertheless, this is of little practical value as a means of improving the fertilizer material itself. The addition of organic matter to the fertilizer material would be prohibitive because of the large amounts that are necessary. However, since organic matter has proved so active, and since the initial disappearance of Cyanamid from solution appears to be one of adsorption, this immediately suggested the use of activated charcoal.

ADSORPTION OF CYANAMIDE BY ACTIVATED CHARCOAL

Four grams of 100-mesh activated charcoal (material from the Barneby-Cheney Engineering Company, Columbus, Ohio) were mixed with 100 grams of quartz sand to which were added 10 milligrams of cyanamide nitrogen.

Another sample of this charcoal was placed in a beaker containing ferric chloride in solution. The iron was precipitated in the presence of the charcoal and the iron hydroxide-charcoal mixture placed on a filter paper and washed free of chlorides. Finally, the mixture was heated to a red heat and then allowed to cool. Four grams of this charcoal-iron oxide mixture were added to quartz sand and treated with cyanamide nitrogen in the same manner as previously.

Fig. 2 gives the rate of disappearance of cyanamide from solution under these conditions in comparison to the most active peat shown in Fig. 2. It is apparent that the activated charcoal is far more active than the hydrogen-saturated Michigan peat, and that when iron oxide is added to the activated charcoal, adsorption of cyanamide takes place very rapidly.

In the case of activated charcoal only (Fig. 2) the cyanamide is practically all removed from solution within 36 hours. If the CN_2 radical is responsible for the toxic action produced by the fertilizer material, then in this activated charcoal-sand system seeds should germinate normally if planted 36 hours after applying the Cyanamid. This test was tried and germination was found to be normal and 100% even when the seeds were planted immediately after applying the Cyanamid. In jars containing sand only, absolutely no germination took place when the seeds were planted at varying intervals of time over a period of 3 weeks. This confirms the work of Crowther and Richardson (6) that the toxic action of the fertilizer material is due to cyanamide itself. In this connection, various investigators (2, 12, 15, 16, 20) have shown that the addition of Cyanamid to the soil first decreases the number of micro-organisms, as a result of the liberation of free cyanamide, and then markedly increases the numbers. It is very likely that in the presence of a strong adsorbent, such as activated charcoal, the initial sterilizing effect of free Cyanamid will not be so marked and the increase in biological activity after the addition of Cyanamid to the soil will take place far more quickly.

The removal of cyanamide from solution by activated charcoal has been shown to take place very quickly, and it is desirable to know whether cyanamide so adsorbed can be further hydrolyzed to urea.

TRANSFORMATION OF CYANAMIDE AFTER ADSORPTION BY ACTIVATED CHARCOAL

Sand-activated charcoal systems which had been treated with 10 milligrams of cyanamide nitrogen were left standing for 2 weeks and then analyzed for the various forms of nitrogen.

There was, of course, no trace of cyanamide nitrogen in solution. A Kjeldahl determination on the entire system gave 10.05 milligrams of nitrogen, showing that no nitrates had formed. Nitrate tests with phenoldisulfonic acid gave negative results. One system was treated to distillation with MgO and no ammonia was evolved.

Urea nitrogen was determined by hydrolyzing it to ammonium carbonate, using Arlco-Jack Bean Meal as a source of urease. Of the 10 milligrams of nitrogen originally present, 2.6 were found in this form. In other words, after 2 weeks, 26% of the cyanamide nitrogen originally added had been changed over to urea.

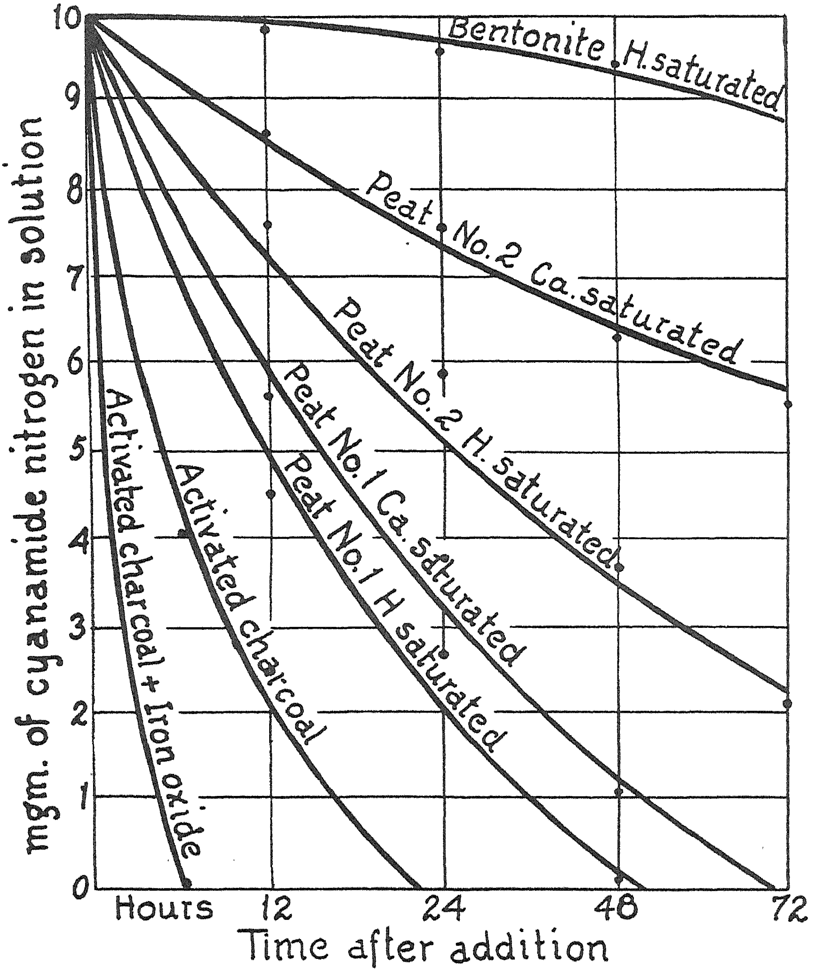

FIG. 2.—Influence of materials indicated when added (7.4%) to quartz sand treated with 10 milligrams of cyanamide nitrogen on the rate of disappearance of cyanamide from solution.

One sand-activated charcoal system was placed on a filter paper and leached with 1 liter of water in 50-cc portions. A total nitrogen determination on this leached system gave 7.6 milligrams of nitrogen. This shows two things. First, that 2.4 milligrams of nitrogen have been lost in the process of leaching, corresponding closely to the 2.6

milligrams of cyanamide nitrogen accounted for in the form of urea. Thus, cyanamide nitrogen adsorbed by activated charcoal is hydrolyzed to urea and, therefore, follows the same course of transformation as Cyanamid applied to the soil. Second, it shows very clearly that cyanamide nitrogen once adsorbed by activated charcoal is held very strongly and cannot be removed easily by leaching with water. This same observation was made in connection with hydrogen-saturated Michigan peat. In practice equally good results are obtained when Cyanamid is applied in the fall or spring of the year, and the above observation offers one explanation for the non-leaching qualities of this fertilizer material.

It was further decided to determine how much activated charcoal must be added to the fertilizer material to allow for 100% germination when these Cyanamid-charcoal mixtures are applied to quartz sand.

AMOUNTS OF ACTIVATED CHARCOAL NEEDED TO COUNTERACT TOXICITY TO GERMINATION

In order to determine how much activated charcoal is needed in the fertilizer material itself to allow for 100% germination of seeds in quartz sand, the following test was tried. Finely ground activated charcoal was added to powdered Cyanamid at the rates of 1, 2, 4, 6, and 10 parts, respectively, to 10 parts of the Cyanamid. Sufficient amounts of these various mixtures to give 10 milligrams of cyanamide nitrogen were added to 100 grams of quartz sand. Oats were planted immediately after adding the Cyanamid-activated-charcoal mixtures and the following results were obtained:

Treatment	Germination, %
Cyanamid only	0
Cyanamid 10 parts, charcoal 1 part	0
Cyanamid 10 parts, charcoal 2 parts	10
Cyanamid 10 parts, charcoal 4 parts	50
Cyanamid 10 parts, charcoal 6 parts	80
Cyanamid 10 parts, charcoal 10 parts	100

While the amount of activated charcoal required to bring about 100% germination in quartz sand is far too great to be of practical value in improving Cyanamid, nevertheless, this matter is worthy of further investigation and it is possible that an adsorbent can be found which will greatly lessen the toxic action of the CN_2 radical. The addition of such compounds as oxides of iron and manganese to charcoal deserves further investigation.

In this work powdered activated charcoal and Cyanamid were intimately mixed and used as such. If this mixture were pelleted in the manner granular Cyanamid is, the efficiency of these adsorbents would be increased many fold, because, when the cyanamide goes into solution, these adsorbents would be immediately at hand.

SUMMARY

Investigators have shown that the toxic action of Cyanamid is due, for the most part, to the cyanamide anion (CN_2). It is known that

lawns, playgrounds, parks, landing fields, and fairways. Much of the lawn and sports turf in this region is composed largely of this type of grass. Growing fine bent seed has become an important industry in several farming sections during the past 15 years. In the New England states and New York, Rhode Island colonial bent is naturalized to the extent that it often predominates in pastures and in moderately fertile reverting meadows.

HISTORICAL

Rhode Island colonial bent grass in New England became naturalized in early colonial times. Farmers prized the grass especially for pasturing sheep. The seed was very often harvested and sold.

When cheap redtop seed came on the market, the bent seed industry in the New England states rapidly declined due to the attendant adulteration and misbranding. The records show that German bent seed growers were given little competition from before 1890 until the World War. After the war new areas in Rhode Island, Prince Edward Island, and New Zealand were opened to the production of bent seed and gradually areas in the Pacific Northwest and in New Brunswick became important.

An indication of the proportions of fine bent used may be had from data (3)[3] obtained from golf courses in the United States. The total purchases were made up as follows: 25% pure colonial bent; 46% mixed bent, largely colonial; 25% creeping bent; and 3% velvet bent. Approximately three quarters of the purchases are shown to have been colonial bent, either pure or mixed.

Bent grass seed is an important cash crop for many farmers in certain moist and relatively cool portions of the United States. To compete successfully in the market the seed must be clean, highly free from weed seeds and carry a minimum of mixture with redtop. It is desirable also that the seed contain a minimum of mixture with other bent seeds.

There are a number of factors in the cultivation of colonial and other bent grasses which combine to make the venture successful or otherwise. Although much of the seed at present is cut from naturalized areas, the growers of Rhode Island have been planting the crop for a number of years. Before planting, the soil must be rendered highly free from weed and other grass seeds. The seed must be planted at a time when weed competition will be at a minimum. Fertilizer must be used in order to encourage dense and rapid growth and largely prevent weed competition. Methods of harvesting, threshing, cleaning, and marketing are all highly important.

Very little experimental work has been reported which has to do with the growing of bent grass for seed. Articles describing the production of bent seed in various areas were published by Potter (12), Odland (8), Edler (4), Schoth (14), and LeLacheur (7), and systems of certification were described by Hyslop (5) and LeLacheur. Yields of 30 to 60 pounds of seed per acre are quoted by LeLacheur for Prince Edward Island and New Brunswick. Schoth found the yield in Oregon between 50 and 75 pounds per acre. A yield of 75 pounds per acre of colonial bent has been reported for New Zealand (6).

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[3] Numbers in parenthesis refer to "Literature Cited," p. 945.

Olcott (9) was among the first to champion the growing of pure seed of grasses in the United States. He was especially eager to promote the culture of bent grass seed in Connecticut. His writings show how much the identity of grass seeds on the market in 1890 were confused.

Reid (13) compared velvet, colonial, and creeping bents as to their tolerance of acid soil conditions and found colonial bent intermediate between velvet and creeping bent in this regard. With colonial bent in pots filled with a phosphorus deficient, acid clay soil, there was found but little response to lime. Lime depressed growth in the early stages, but promoted growth towards the end of the experimental period.

MATERIALS AND METHODS

In 1928, an experiment was started at the Rhode Island Experiment Station[4] which had for its object a study of the influence of different fertilizer mixtures on the yield of Rhode Island colonial bent seed.

The soil where the experiment is located is a moderately fertile, uniform silt loam underlain with gravel. A composite sample taken from the area in 1928 showed an acidity of pH 4.5. Tests of individual plats made in 1933 showed a range from pH 4.14 to 4.83.

Thirty-six 1/180 acre plats, each 11 x 22 feet, were planted in August of 1928. Fertilizer treatments were applied in quadruplicate in 1929. Fertilizer was applied in two doses in the early spring of each succeeding year. The various ratios of nitrogen, phosphoric acid, and potash applied are shown in the following tables. Each unit of a given ratio represents 15 pounds of the respective ingredient. Thus, the ratio 1–6–3 represents an application of 15 pounds of nitrogen, 90 pounds of phosphoric acid, and 45 pounds of potash annually. One foot borders were removed before harvest on all plats during the seasons of 1930 to 1932. In 1933, this was not done due to the shortage of labor. The border effect probably accounts in part for the comparatively larger yields in that season.

Considerable time was consumed in working out the cleaning technic to use with the grain cleaning mill available. Special screens and careful adjustment of the air blast were found essential.

RESULTS

Data on stand, growth, and ripening are presented in Table 1. The notes on growth show a marked effect from nitrogen each season. On plats which received 90 pounds per acre of nitrogen, the growth was so dense that, with the exception of yarrow the weeds were largely smothered out. On plats which received 60, 30, 15, and 0 pounds of nitrogen per acre there was a progressive increase in the population of weeds and poverty grasses in the order named. Likewise, the bent grass was shorter and less dense. Increasing the amounts of nitrogen applied was found to hasten heading. Lodging occurred to some extent on the plats which received the high ratio of nitrogen.

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[4] This experiment was planned and started by E. S. Garner, formerly Agrostologist at this Station.

TABLE 1.—*Data on the growth of Rhode Island colonial bent grown with different ratios of nitrogen, phosphoric acid, and potash for the period of 1930-33 (averages).*

Fertilizer ratio	Stand, %	Height, inches	Date ripe	Lodging	
				%	Degree
0-0-0	65	14	July 30	0	0
1-6-3	82	15	July 29	0	0
2-6-3	89	16	July 28	1	2
4-6-3	99	20	July 27	3	8
6-6-3	100	21	July 27	17	27
6-2-3	100	21	July 27	13	37
6-10-3	100	21	July 27	25	31
6-6-1	100	21	July 28	22	25
6-6-5	99	22	July 29	35	44

Phosphorus and potash produced little effect on the growth except that date of heading averaged slightly earlier with a high ratio of phosphorus and slightly later with a high ratio of potash.

The yields obtained with the various fertilizer ratios applied are presented in Table 2. Very light yields of seed which were obtained the season following planting (1929) are not included in the table. From these and other similar results it appears that a light yield may be expected the season following a late planting of colonial bent.

The figures in Table 2 show that nitrogen has been the most effective in increasing the yields of seed. The yield has been largely in proportion to the amount of nitrogen applied. The average yield for the four seasons for which the yields are recorded have ranged from 34.2 pounds per acre where the 1-6-3 ratio was used to 130.2 pounds where 1,500 pounds per acre of a 6-6-1 ratio were applied. Variations in the amount of phosphoric acid or potash applied has had little consistent effect on the yield of seed. There seems to be some indication that with only a small amount of nitrogen in the fertilizer applied, a heavy application of phosphoric acid and potash has a detrimental effect upon seed production. This may explain why the yields with the 1-6-3 ratio averaged 6.5 pounds less per acre than the checks.

The significance of the increases in yield may be seen from the magnitude of the probable errors calculated. These were obtained by use of the pairing method. The probable errors have ranged from 6.5 to 12.5% for the various years.

Although there was a consistent increase in seed yield with increasing amounts of nitrogen applied in the fertilizer, there is a limit to the amount that can be safely applied due to the danger of lodging and the reduction in yield which may result. It is difficult to harvest a crop of bent grass that has become badly lodged.

In Table 3 the differences in average yields between various treatments have been arranged in a convenient way for ready comparison. The increase or decrease in yields obtained with the fertilizer ratio shown in the horizontal row at the top of the table as compared with any ratio shown in the column at the left of the table, may be obtained from these figures.

TABLE 2.—*Yields of cleaned seed of Rhode Island colonial bent in pounds per acre with different ratios of nitrogen, phosphoric acid, and potash.*

Fertilizer ratio	Annual application*, lbs. per acre			Cleaned seed in pounds per acre				
	N	P_2O_5	K_2O	1930	1931	1932	1933	Average
0–0–0	0	0	0	28± 2.5	7±1.0	37± 3.2	91± 6.9	40.7±2.0
1–6–3	15	90	45	32± 2.9	7±1.0	26± 2.3	72± 4.7	34.2±1.5
2–6–3	30	90	45	71± 6.4	10±1.2	33± 2.9	91± 6.9	51.2±2.5
4–6–3	60	90	45	103± 9.3	34±4.2	75± 6.5	114± 7.4	81.5±3.8
6–6–3	90	90	45	154±13.9	57±7.4	106± 9.2	163±10.6	120.0±5.7
6–2–3	90	30	45	138±12.4	45±5.7	133±11.6	185±12.0	125.2±5.9
6–10–3	90	150	45	178±16.0	48±6.0	127±11.0	132± 8.6	121.2±5.7
6–6–1	90	90	15	165±14.8	59±7.4	122±10.6	175±11.4	130.2±6.1
6–6–5	90	90	75	143±11.9	42±5.2	128±11.1	162±10.5	118.7±5.6

*Nitrogen from sulfate of ammonia, phosphoric acid from superphosphate, and potash from muriate of potash.

TABLE 3.—*Increase or decrease between average yields of Rhode Island colonial bent seed under various fertilizer treatments.*

Fertilizer ratio	Cleaned seed in pounds per acre									Average yield, 1930–33, lbs. per acre
	0–0–0	1–6–3	2–6–3	4–6–3	6–6–3	6–2–3	6–10–3	6–6–1	6–6–5	
0–0–0	0	—6.5±2.5	10.5±3.0	40.8±4.2	79.8±6.0	84.5±6.2	80.5±6.0	89.5±6.4	78.0±5.9	40.7±2.0
1–6–3		0	17.0±2.9	47.3±4.1	86.3±5.9	91.0±6.1	87.0±5.9	96.0±6.3	84.5±5.8	34.2±1.5
2–6–3			0	30.3±4.5	69.3±6.2	74.0±6.4	70.0±6.2	79.0±6.6	67.5±6.1	51.2±2.5
4–6–3				0	39.0±6.8	43.7±7.0	39.7±6.8	48.7±7.2	37.2±6.8	81.5±3.8
6–6–3					0	4.7±8.2	0.7±8.1	9.7±8.4	—1.8±8.0	120.5±5.7
6–2–3						0	—4.0±8.2	5.0±8.5	—6.5±8.1	125.2±5.9
6–10–3							0	9.0±8.4	—2.5±8.0	121.2±5.7
6–6–1								0	-11.5±8.3	130.2±6.1
6–6–5									0	118.7±5.6

The average weight per bushel of the cleaned seed has varied from an average of 21.3 pounds per bushel in 1931 to 29.0 pounds per bushel in 1932. The average weight in 1933 was 27.9 pounds per bushel. The seed yields in 1931 were very low in spite of a thrifty growth of grass. A period of wet weather during pollination apparently was the cause of the poor set of seed. The weight per bushel was also low, as was to be expected. There was no consistent difference in weight per bushel of the seed obtained from the different fertilizer ratio applications.

EFFECTS OF LIME ON SEED YIELDS

In order to determine whether lime would bring about an increase in seed production, each plat in the first series was divided into halves. Limestone was spread on one-half of each plat at the rate of 1,000 pounds of calcium oxide equivalent per acre late in the autumn of 1931. When analyzed by Student's method, as shown in Table 4, the odds that lime had increased the amount of seed 8 pounds were 5 to 1 in 1932 and 6 to 1 in 1933. These odds are not considered significant and indicate only a slight advantage for liming.

TABLE 4.—*Effect of one application of lime on the production of Rhode Island colonial bent seed.*

Fertilizer ratio	Yields in pounds per acre			
	1932		1933	
	Lime*	No lime	Lime	No lime
0-0-0	46.9	35.2	126.7	113.3
1-6-3	27.7	19.2	69.7	76.0
2-6-3	44.8	41.6	111.7	98.2
4-6-3	62.9	75.7	87.9	87.1
6-6-3	91.7	78.9	176.6	151.3
6-2-3	156.7	106.6	150.5	130.7
6-10-3	108.7	75.7	132.3	129.1
6-6-1	74.6	99.1	208.3	175.8
6-6-5	140.7	148.2	156.0	190.1
Average	83.86	75.58	135.52	127.96
Mean difference	8.28		7.56	
Odds	5 to 1		6 to 1	

*One ton per acre of 50% ground limestone.

DISCUSSION

The data indicate that small proportions of phosphorus and potash in the fertilizer were sufficient for the production of seed of Rhode Island colonial bent under the conditions of this test. Medium and high levels of phosphorus and potash tended to reduce yields and, where the nitrogen was insufficient, to reduce yields below those obtained on the unfertilized plats. Applications of nitrogen up to 90 pounds per acre were progressively more profitable as the amount of nitrogen was increased. There was a little difficulty with lodging where the highest amount of nitrogen was applied.

Yields of the unfertilized plats compared favorably with those reported as obtained in the Maritime Provinces of Canada but were only approximately half those which were obtained in the Pacific Northwest and in New Zealand.

A fertilizer high in nitrogen, such as a 10–6–4 or a 12–6–4, should prove satisfactory for general use under these conditions in fertilizing Rhode Island colonial bent for seed production. An application of 800 to 1,000 pounds per acre should be sufficient.

SUMMARY

Rhode Island colonial bent grown for seed was fertilized with various proportions of nitrogen, phosphoric acid, and potash. The ratios included in the test varied in the amounts of each fertilizer element applied.

The yield of seed produced was influenced chiefly by the amount of nitrogen applied. Phosphorus and potash had little effect.

There was an indication that with high applications of the minerals without a corresponding application of nitrogen the yields were depressed.

There was some difficulty with lodging with the highest application of nitrogen.

There was little difference in time of maturity between plats receiving different fertilizer ratios.

The weight per bushel of seed produced did not vary to any appreciable extent between the various treatments.

Liming had only a small tendency to increase the seed yields.

LITERATURE CITED

1. Anonymous. Harvesting bent seed. Bul. U. S. Golf Assoc., Green Sect., 10: 194–195. 1930.
2. ———. Sources of golf course grass seed. Bul. U. S. Golf Assoc., Green Sect., 10: 218–224. 1930.
3. ———. Kinds and quantities of turf seeds purchased by golf courses. Bul. U. S. Golf Assoc., Green Sect., 11: 222–223. 1931
4. Edler, G. C. Bent seed production in Germany. Bul. U. S. Golf Assoc., Green Sect., 10: 205. 1930.
5. Hyslop, G. R. Oregon bent grass certification. Bul. U. S. Golf Assoc., Green Sect., 10: 195–200. 1930.
6. Journal of Agriculture New Zealand, 44: 77. 1932.
7. LeLacheur, G. Canadian certified bent seed. Bul. U. S. Golf Assoc., Green Sect., 10: 212–213. 1930.
8. Odland, T. E. Bent grass seed production in Rhode Island. Bul. U. S. Golf Assoc., Green Sect. 10: 201–204. 1930.
9. Olcott, James B. Fine versus coarse agrostis. Conn. State Agr. Exp. Sta. Ann. Rpt., 1887: 177–181. 1887.
10. Pieper, J. J., and Burlison, W. L. Redtop seed production in Illinois. Bul. U. S. Golf Assoc., Green Sect., 10: 225–228. 1930.
11. Piper, C. V., and Hillman, F. H. The agricultural species of bent grasses. U. S. D. A. Bul. 692: 27. 1928.
12. Potter, C. A. Saving seed of the Rhode Island bent. Conn. Bd. Agr., 23d Ann. Rpt., 1889: 45–59. 1889.
13. Reid, Mary E. The effects of soil reaction upon the growth of several types of bent grasses. Bul. U. S. Golf Assoc., Green Sect., 12: 196–212. 1932.
14. Schoth, H. A. Bent grass seed production in the Pacific Northwest. Bul. U. S. Golf Assoc., Green Sect., 10: 206–211. 1930.

A CHEMICAL STUDY OF A SOIL UNDER LONG-CONTINUED FIELD EXPERIMENTS[1]

H. J. SNIDER[2]

This work included a laboratory study of both soil and crop samples obtained from two series of fertility plats on the Odin experiment field. This field was established in 1902, and was one of the oldest of the outlying soil fields of the Illinois Experiment Station. The series of plats studied were started in 1904 and were under a system of soil treatment and crop rotation until after the soil samples were collected in the fall of 1931, thus covering a period of 27 years of experimental work.

OBJECT OF STUDY

The plan of soil treatment and crop yield data suggested the following lines of investigation:

1. The accumulation of the applied phosphorus and the influence of limestone upon the native and applied phosphorus.
2. The penetration of the applied phosphorus into the subsurface soil.
3. The accumulation and availability of potash salts when used with limestone and phosphate treatments.
4. The effect of different amounts of limestone upon soil reaction and replaceable calcium and magnesium.
5. The effect of long-continued soil treatment and crop rotation upon the nitrogen and organic-matter content of the soil.
6. A study of the assimilation of phosphorus and potassium by crops.

DESCRIPTION OF THE FIELD

This experimental field was located on Cisne silt loam, a soil low in fertility, poorly drained and having a very compact subsoil. A general description of the field and plan of plat layout has been presented by Bauer, *et al.* (2).[3]

In 1904, hydrated lime at the rate of 1½ tons an acre was put on series 800; and in 1908, 1913, and 1919, limestone was applied which brought the total applications up to 8 tons an acre. Series 600 was unlimed up to 1922, when 1 ton an acre of limestone was applied and an additional 2 tons were put on in 1927 making a total of 3 tons an acre.

From 1904 to 1919, inclusive, phosphatic fertilizers were broadcast in relatively small applications at more or less regular intervals until the total amounts an acre were as follows: Superphosphate, 7,000 pounds; rock phosphate, 14,000 pounds; and basic slag, 5,250 pounds. No analytical data were recorded showing the exact phosphorus content of these materials. It is assumed that the content was about as follows: Superphosphate, 16% P_2O_5; rock phosphate, 12.5% phosphorus; and basic slag, about 9% phosphorus.

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[1] Contribution from the Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director. Received for publication August 2, 1934.

[2] Assistant Chief, Soil Experiment Fields.

[3] Reference by number is to "Literature Cited," p. 953.

During 1904 and 1905 potassium sulfate was put on all plats of each series at the rate of 500 pounds an acre. In 1908, kainit was applied at the rate of 1,000 pounds and an additional 1,000 pounds were put on in 1913. The equivalent of approximately 400 pounds an acre of elemental potassium was applied during the first 10-year period.

The original crop rotation was corn, oats, and timothy. This was replaced in 1923 by a short rotation of corn and wheat, with sweet clover seeded in the wheat and used as a green manure crop.

SAMPLING METHODS

The experimental plats were 1/10 acre in size. The soil samples were taken to represent three strata, namely, 0–7 inches, 7–14 inches, and 14–21 inches. In sampling the surface soil, 20 or more borings uniformly distributed over the plats were composited to form the samples representing the unphosphated soils, and 30 or more borings were taken from each of the phosphated plats to form the composite samples. Six pits approximately 12 inches in diameter were sunk at regular intervals on each plat and the soil at the depths of 7–14 inches and 14–21 inches was removed from the sides of the pits to form the composite for the subsurface samples.

ANALYTICAL METHODS

Soluble phosphorus was determined by the Truog method (10). The potassium was determined by a method similar to that reported by Schueler and Thomas (8). The potassium, calcium, and magnesium were replaced by neutral, normal ammonium acetate as described by Schollenberger and Dreibelbis (6). The Neubauer method was used in much the same manner as outlined by Thornton (9). The pH was determined with the quinhydrone electrode and the organic matter was determined by the Schollenberger (7) method.

RESULTS OF PHOSPHORUS STUDIES

The total phosphorus values in Table 1 indicate that from the applications of superphosphate to these plats there remained in the surface soil a residue of about 300 to 350 pounds an acre of total phosphorus. The values show that the applications of rock phosphate left a residue of approximately 1,500 pounds an acre of phosphorus, and from the use of basic slag there remained a residue of approximately 350 pounds an acre of phosphorus.

The phosphorus solubility values in Table 1 show widely variable amounts of phosphorus recovered from the soils of phosphated and unphosphated plats. The solubility values on untreated plat 306 and on unphosphated plats 602 and 605 were lower than the values for the heavily limed but unphosphated plats 802 and 805. The results indicate that the 8 tons of lime approximately doubled the solubility of the native phosphorus on this soil. This increase is also evident by the greater phosphorus solubility found in the soils at the end of a 4-hour extraction period from plats 802 and 805 as compared to the values for plats 602 and 605 for a similar extraction period.

The 4-hour extraction of the soil from the rock phosphate treated plat 604 gave approximately 1,300 pounds of soluble phosphorus which was 85.6% of the total residual phosphorus found in the soil. The value for the superphosphate solubility, plat 603, under similar conditions was 27.3% of the total residual phosphorus, and the solubility of the basic slag, plat 606, was 22.8% of the total residual phosphorus.

The solubility values for the superphosphate and the rock phosphate were slightly higher on the heavily limed soils of series 800 as compared with the lightly limed soils of series 600. The heavy lime applications on plat 806 apparently greatly increased the solubility of the phosphorus added in the basic slag as compared to that of plat 606.

The Neubauer values in Table 1 for the unphosphated soils were far below 1.75 mgm of phosphorus, the limit value suggested by Thornton (9). The superphosphate plat 603 and the rock phosphate plat 604 were above the limit value, while the basic slag treatment plat 606 was below. The superphosphate and basic slag treatment on the heavily limed soil plats 803 and 806 was found to be above the limit value, while the value for the rock phosphate treatment on the heavily limed soil was below the limit value. These values from field soils are in accord with the results of Truog (11) and others reporting on this problem of the availability of phosphorus in the presence of lime.

TABLE 1.—*Total and soluble phosphorus in soils and available phosphorus as determined by the Neubauer method:*

Plat No.	Treatment	Total phosphorus		Soluble phosphorus		Neubauer available, mgm
		%	Lbs. per acre	½-hour extraction, lbs. per acre	4-hour extraction, lbs. per acre	
306	None	0.0363	726	12	14	0.50
			3 Tons Lime			
602	LK	0.0375	750	12	16	0.50
603	LK+SuperP	0.0525	1,050	62	98	2.00
604	LK+RockP	0.1125	2,250	550	1,300	2.00
605	LK	0.0375	750	14	16	0.50
606	LK+SlagP	0.0550	1,100	61	96	1.50
			8 Tons Lime			
802	LK	0.0325	650	20	32	0.50
803	LK+SuperP	0.0500	1,000	72	116	2.50
804	LK+RockP	0.1113	2,226	680	1,400	1.50
805	LK	0.0325	650	24	42	0.50
806	LK+SlagP	0.0500	1,000	180	310	2.50

The downward movement of the applied phosphorus, Table 2, was relatively small when compared with the large total phosphorus content of the surface soil. The values for total phosphorus indicate that the superphosphate and rock phosphate moved into the 7-to 14-inch stratum in about equal amounts. The values for total phosphorus gave no evidence of a movement of phosphorus into the 14-to 21-inch stratum of soil. The solubility values showed higher values for the rock phosphate in the 7- to 14-inch stratum than for superphosphate. The higher solubility value in the 14- to 21-inch stratum, plat 604, may have been due to the penetration of a small amount of rock phosphate or to the greater solubility of subsoil phosphorus frequently found in soils.

TABLE 2.—*Total and soluble phosphorus content of surface and subsurface soils.*

Plat No.	Treatment	Depth, inches	Total phosphorus		Soluble P, 4-hour extraction, lbs. per acre
			%	Lbs. per acre	
602	LK	0–7	0.0375	750	16
		7–14	0.0312	624	12
		14–21	0.0312	624	8
603	LK+SuperP	0–7	0.0525	1,050	98
		7–14	0.0350	700	14
		14–21	0.0300	600	6
604	LK+RockP	0–7	0.1125	2,250	1,300
		7–14	0.0350	700	26
		14–21	0.0287	574	18
802	LK	0–7	0.0325	650	32
		7–14	0.0287	574	10
		14–21	0.0300	600	6
803	LK+SuperP	0–7	0.0500	1,000	116
		7–14	0.0350	700	18
		14–21	0.0300	600	6
804	LK+RockP	0–7	0.1113	2,226	1,400
		7–14	0.0350	700	42
		14–21	0.0275	550	4

RESULTS OF POTASSIUM STUDIES

The results in Table 3 indicate that the potash salts added to these plats increased the replaceable potassium, but the analytical methods failed to show any difference in the values for total potassium on the various plats.

There was a tendency toward lower replaceable potassium values on the heavily limed soils of series 800 as compared with the lightly limed soils of series 600 which was due to larger crop removal. The Neubauer values for available potassium were also lower on series 800 than on series 600 with the exception of plat 804.

The Neubauer values, Table 3, for available potassium coincided reasonably well with the replaceable values. All of the Neubauer values were far below the limit value of 8 mgm of potassium suggested by Thornton (9).

NITROGEN AND ORGANIC MATTER

The values in Table 4 show that on series 600, lightly limed, the total nitrogen and organic matter values were maintained at a higher level than on the untreated plat 306 or on any of the plats of series 800. The comparison between series 600 and 800 indicated that heavy liming of this soil with subsequent heavy cropping tended toward a more rapid depletion of the total supply of nitrogen and organic matter.

TABLE 3.—*Total and replaceable potassium in soils and available potassium as determined by the Neubauer method.*

Plat No.	Treatment	Total K		Replaceable K		Neubauer, mgm
		%	Lbs. per acre	Mil. equiv.	Lbs. per acre	
306	None	1.30	26,000	0.104	81	0
			3 Tons Lime			
602	LK	1.31	26,200	0.154	120	2.61
603	LK+SuperP	1.31	26,200	0.121	94	2.00
604	LK+RockP	1.31	26,200	0.150	117	1.30
605	LK	1.31	26.200	0.129	101	1.63
606	LK+SlagP	1.31	26,200	0.117	91	1.63
			8 Tons Lime			
802	LK	1.31	26.200	0.117	91	0.33
803	LK+SuperP	1.31	26,200	0.117	91	0.33
804	LK+RockP	1.31	26,200	0.162	127	3.92
805	LK	1.31	26,000	0.117	91	0.33
806	LK+SlagP	1.31	26,200	0.100	78	0.33

SOIL REACTION AND REPLACEABLE CALCIUM AND MAGNESIUM

The results in Table 4 also indicate that the 3-ton application of limestone brought the soil reaction from pH 5.0 up to about pH 6.0 and that the 8 tons of lime brought the soil reaction up near the neutral point. The use of superphosphate tended to create a more acid reaction, while basic slag tended to give a more alkaline reaction in this soil.

TABLE 4.—*Soil reaction, total nitrogen, total organic matter, and replaceable calcium and magnesium in plat soils.*

Plat No.	Treatment	pH	Nitrogen		Organic matter %	Calcium		Magnesium	
			%	Lbs. per acre		Mil. equiv.	Lbs. per acre	Mil. equiv.	Lbs. per acre
306	None	5.0	0.085	1,700	1.95	2.41	960	1.78	454
				3 Tons Lime					
602	LK	6.0	0.109	2,180	2.52	3.61	1,440	2.57	626
603	LK+SuperP	5.9	0.106	2,120	2.47	4.42	1,760	2.57	626
604	LK+RockP	6.2	0.097	1,940	2.47	4.50	1,800	2.77	674
605	LK	6.1	0.103	2,060	2.47	3.31	1,320	2.38	578
606	LK+SlagP	6.3	0.104	2,080	2.47	4.80	1,920	2.77	674
				8 Tons Lime					
802	LK	6.5	0.096	1,920	2.17	7.22	2,920	2.18	530
803	LK+SuperP	6.3	0.090	1,800	2.16	8.28	3,320	1.88	458
804	LK+RockP	6.5	0.089	1,780	2.15	8.90	3,560	1.68	410
805	LK	6.6	0.089	1,780	2.14	8.00	3,200	2.18	530
806	LK+Slag P	7.0	0.086	1,720	2.14	8.83	3,520	1.88	458

The applied phosphates tended to increase the replaceable calcium. This increase was more pronounced on series 600. The limestone on all plats greatly increased the replaceable calcium.

The replaceable magnesium values were lower on series 800 than on series 600, while the reverse was true with calcium. The replaceable magnesium values on the phosphated plats of series 800 were near the value of unlimed plat 306, indicating a depletion of available magnesium in the soils of these plats.

ASSIMILATION OF PHOSPHORUS AND POTASSIUM BY CROPS

The grain yields recorded in Table 5 indicated a favorable increase in wheat for the three forms of phosphates applied on series 600, lightly limed, while on series 800, heavily limed, the apparent increase due to rock phosphate and basic slag was very small. The crop yields were in accord with the phosphorus solubility values given in Table 1 which indicated that the heavy applications of limestone rendered more soluble the native phosphorus, thus largely offsetting the effect of the applied phosphates. This is supported by additional crop yield data reported by Bauer (3, 4, 5) which showed that the 3-year average wheat yield on plats 602 and 605 was 18.4 bushels, while the average for plats 802 and 805 was 24.3 bushels.

The wheat grain on unphosphated plats 802 and 805 assimilated a higher percentage of phosphorus than did the grain from unphosphated plats 602 and 605, as indicated in Table 5. This was also in accord with the solubility values given in Table 1 and with the work of Ames and Kitsuta (1) who reported that the use of limestone increased the assimilation of phosphorus from its natural supply in the soil.

TABLE 5.—*Wheat yield with phosphorus and potassium content of grain, 1930 crop.*

Plat No.	Treatment	Wheat, bu. per acre	Phosphorus		Potassium	
			%	Lbs. per acre	%	Lbs. per acre
			3 Tons Lime			
602	LK	16.6	0.400	3.98	0.339	3.83
603	LK+SuperP	21.5	0.450	5.80	0.365	4.70
604	LK+RockP	21.7	0.500	6.51	0.378	4.92
605	LK	15.2	0.400	3.91	0.326	3.19
606	LK+SlagP	25.2	0.500	7.56	0.365	5.52
			8 Tons Lime			
802	LK	17.2	0.450	4.64	0.352	3.63
803	LK+SuperP	21.7	0.550	7.16	0.417	5.42
804	LK+RockP	21.3	0.500	6.39	0.391	5.00
805	LK	21.0	0.450	5.67	0.339	4.27
806	LK+SlagP	20.1	0.500	6.03	0.352	4.24

The percentage of potassium found in the wheat grain was slightly lower from the unphosphated than that from the phosphated plats, with the exception of plat 806 (Table 5).

In all comparisions in Table 6 the phosphorus content of the sweet clover was greatly increased by the applied phosphorus. On plat 803, treated with superphosphate and 8 tons of lime, the percentage of phosphorus found in the sweet clover was considerably higher than that from plat 603, treated with superphosphate and 3 tons of limestone. The same was true with the slag phosphate treatments on plats 806 and 606. The sweet clover from the rock phosphate treated plats had the higher percentages of phosphorus on the lightly limed soils and the lower percentages on the heavily limed soils.

TABLE 6.—*Phosphorus and potassium content of sweet clover sampled April, 1931.*

Plat No.	Treatment	Part of plant	Phosphorus %	Potassium %
602	LK	Tops	0.20	0.94
		Roots	0.12	0.32
603	LK+SuperP	Tops	0.25	0.91
		Roots	0.30	0.39
604	LK+RockP	Tops	0.37	0.88
		Roots	0.47	0.26
605	LK	Tops	0.22	1.20
		Roots	0.20	0.32
606	LK+SlagP	Tops	0.30	0.60
		Roots	0.35	0.22
802	LK	Tops	0.27	0.88
		Roots	0.15	0.19
803	LK+SuperP	Tops	0.42	0.35
		Roots	0.60	0.32
804	LK+RockP	Tops	0.32	0.91
		Roots	0.32	0.19
805	LK	Tops	0.22	0.58
		Roots	0.15	0.19
806	LK+SlagP	Tops	0.37	0.32
		Roots	0.50	0.22

The percentages of potassium found in the sweet clover were lower on corresponding plat treatments on series 800 than on series 600. The one exception to this was the sweet clover tops from plat 804.

SUMMARY AND CONCLUSIONS

The application of relatively large quantities of superphosphate, rock phosphate, and basic slag over a long period of years created in the surface soil a large supply of residual phosphorus.

The phosphorus applied to the soil in the form of rock phosphate had at the end of a 27-year period a much higher solubility than superphosphate or basic slag phosphate.

The penetration of applied phosphorus into the subsurface soil might be said to be negligible on the soil under consideration.

Eight tons of lime increased the solubility of the native phosphorus in the soil, while 3 tons of limestone applied over a relatively short period of years had but little effect on the solubility of the native phosphorus.

The Neubauer values indicated that the 8 tons of lime depressed the availability of rock phosphate and increased the availability of superphosphate and slag phosphate.

This soil was low in replaceable potassium and the Neubauer method showed it to be low in available potassium, although it is relatively high in total potassium. The 8 tons of lime depressed the availability of potassium as determined by the Neubauer method, and tended to give lower values for replaceable potassium as determined by the chemical method.

The reaction of the untreated soil was pH 5.0. The soil to which 8 tons of lime were added had a pH ranging from 6.3 to 7.0 and where 3 tons of lime had been applied the pH ranged from 5.9 to 6.3. The various phosphates caused some variation in soil reaction.

The lime applications increased the replaceable calcium values. The heavy lime treatment showed little, if any, increase in replaceable magnesium, while light lime maintained the replaceable magnesium values considerably above that of the untreated check.

The total nitrogen and organic matter values were maintained at a slightly higher level on the soils with the light application of lime as compared with the heavy application.

The wheat grain yields and the total phosphorus content of the grain from the unphosphated plats coincided with the phosphorus solubility values of the soils from these plats.

The phosphorus content of the second year spring growth of sweet clover indicated that the heavy liming apparently aided the assimilation of phosphorus from superphosphate and basic slag and tended to depress the assimilation of phosphorus from rock phosphate.

LITERATURE CITED

1. AMES, J. W., and KITSUTA, K. Availability of rock phosphate as indicated by phosphorus assimilation by plants. Jour. Amer. Soc. Agron., 24: 103–122. 1931.
2. BAUER, F. C., SMITH, R. S., and SMITH, L. H. The Illinois experiment fields. Ill. Agr. Exp. Sta. Bul. 273. 1926.
3. ——————. Crop yields from Illinois experiment fields. Ill. Agr. Exp. Sta. Bul. 305. 1927.
4. ——————. Crop yields from Illinois experiment fields. Ill. Agr. Exp. Sta. Bul. 370. 1930.
5. ——————. Crop yields from Illinois experiment fields. Ill. Agr. Exp. Sta. Bul. 382. 1931.
6. SCHOLLENBERGER, C. J., and DREIBELBIS, F. R. Analytical methods in base exchange investigations on soils. Soil Science, 30: 161–173. 1930.
7. ——————. Determination of soil organic matter. Soil Science, 31: 483–486. 1931.
8. SCHUELER, J. E., and THOMAS, R. P. Determination of potassium by sodium cobaltinitrite. Ind. Eng. Chem., Anal. Ed., 5: 163–165. 1933.
9. THORNTON, S. F. Experiences with the Neubauer method for determining the mineral nutrient deficiencies of soils. Jour. Amer. Soc. Agron., 23: 195–208. 1932.
10. TRUOG, E. The determination of readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22: 874–882. 1930.
11. ——————. The utilization of phosphates by agricultural crops, including a new theory regarding the feeding power of plants. Wis. Agr. Exp. Sta. Res. Bul. 41. 1916.

GROWTH OF WHEAT DURING THE HEADING PERIOD[1]

V. H. Florell and Boyd Faulkner[2]

Agronomists and farmers alike are interested in the growth and development of crops. Those agronomists who observe varieties closely realize the need for more information on habits of growth to assist in interpreting differences in production. The rapid exsertion of the spike from the sheath of wheat at Moscow, Idaho, as compared with the same phenomenon observed in other localities, attracted the attention of the writers and led to the growth study presented herein.

The data were secured in the experimental field of the Agronomy Division of the University of Idaho at Moscow in 1931, 1932, and 1933. The main objects were to determine the daily increase in height of culm, the exsertion of the spike from the sheath, and the relation of growth to blooming in several of the more important winter and spring wheat varieties during the heading stage.

MATERIAL AND METHODS

Ten varieties of fall-sown wheat were used for the experiment in 1931, six (Ridit, Hybrid 128, Mosida, Triplet, Turkey, and Albit) having a winter habit and four (Federation, Baart, Marquis, and Jenkin) a spring habit of growth. Four additional spring varieties (Hard Federation, Vernal emmer, White Polish, and Kubanka) were grown in 1932. In 1933, nine fall-sown and seven spring-sown varieties were used. Only one of the fall-sown spring varieties, Federation, survived the winter with sufficient stand to permit study.

The wheat was sown by hand in 5-foot rows. Plants to be measured were selected to avoid border effect in so far as possible.

Increase in height of the culm from first heading until elongation ceased was determined by daily measurements at the tip of the spike and at the ligule of the top leaf or sheath. Plant measurements were taken on a single culm except in a few cases. With a few exceptions, 10 plants of each variety were measured in 1931 and 1932 and 16 plants in 1933.

First heading, except in the club wheats, was regarded as that stage of development at which the tip of the spike was just emerging from the sheath, or when the tip of the spike and the ligule of the top leaf were at the same level. In the club wheats the spike usually breaks out at the side of the sheath, and for these varieties plants were selected on

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[2] Formerly Associate Agronomist and Agent, respectively, Division of Cereal Crops and Diseases. The authors wish to express appreciation to Floyd W. Trail and D. M. Hegsted for assistance in making the daily growth observations; to C. A. Michels, Assistant Agronomist, University of Idaho, for helpful criticism of the manuscript; and to F. L. Burkart, Field Superintendent in Agronomy, University of Idaho, who contributed to the experiment materially by his observation that, in wheat plants in the greenhouse during the winter, elongation of the culm practically ceased as soon as blossoming began. Mr. Burkart also kindly made available the temperature data presented in this paper and provided the equipment used in making the growth measurements.

which the spike was just visible either at the side or at the top of the sheath.

A pine stake 1 inch square and about 5 feet long was driven into the ground near each plant to be measured. The height of the spike was marked on one side of the stake and that of the ligule on another. At maturity the plants with their stakes were taken to the laboratory for measurement. Before pulling the stakes a line was drawn at the surface of the ground to indicate the point from which the measurements were to be made.

All measurements within a variety were begun on the same day with the plants in the same stage of development as nearly as possible. Also, measurements were made at the same time each day, the varieties being taken in the same order. In 1931, the measurements were begun at 5 p. m. and in 1932 and 1933 at 7 a. m. The early morning hour was preferable, as the daily maximum temperature at Moscow may occur either before or after 5 p. m. in early summer, and growth is closely correlated with temperature. The first culm to head was used for the growth measurements in most of the plants. It usually was also the tallest culm.

Plants of 12 varieties of fall-sown spring wheat were examined in 1933 to determine the development of the primary culm, following comparatively severe winterkilling. The observations in 1932 had suggested that the lack of development of the primary culms in fall-sown spring wheat was the result of winter injury, but the 1933 results did not support this view.

EXPERIMENTAL DATA

DAILY INCREASE IN HEIGHT

The greatest increase in height in wheat plants occurs between the stages of "shooting" and "full heading." This period is characterized by rapid development of every part of the plant, but in the culm consists largely of an increase in length.

The daily increases in height during the heading period and the daily maximum and mean temperatures for the years 1931, 1932, and 1933, and the average period of blooming in 1932 and 1933, are shown in Figs. 1, 2, and 3. The total increases in height and the final height of the plants are given in Table 1.

The daily increase in height are correlated with temperature, as would be expected, and in all varieties growth ceased gradually rather than abruptly. Some individual culms elongated as much as 2 cm or more on the final day of growth. The period of growth for the measured culms of different plants of a variety sometimes varied as much as 2 or 3 days. Consequently, the growth of individual culms ceased more abruptly than is indicated by the graphs since these are based upon the average of all culms, including some that had stopped elongating. As shown in Figs. 1, 2, and 3, the period of elongation after heads first appeared ranged from 7 to 9 days in 1931, from 8 to 12 days in 1932, and from 7 to 15 days in 1933.

The maximum daily elongation for a variety during the season of 1931 ranged from 4.25 cm in Albit to 6.75 cm in Marquis and Triplet.

TABLE 1.—*Increase in height during the heading period and final culm height of 18 varieties of wheat at Moscow, Idaho, in 1931, 1932, and 1933.*

Variety	Culm height in centimeters										Average increase, % of total height
	1931		1932		1933				Average*		
					Fall-sown		Spring-sown				
	Increase	Final	Increase	Final	Increase	Final	Increase	Final	Increase	Final	
Federation	23.3	78.9	37.4	101.3	31.8	76.8	31.4	89.8	32.5	85.7	35.9
Baart	29.4	87.6	56.0	129.0	—	—	45.3	106.8	—	—	—
Marquis	36.0	93.5	46.3	126.5	—	—	42.1	107.8	—	—	—
Hybrid 128	24.1	79.3	48.6	132.8	48.9	111.4	—	—	40.5	107.8	33.6
Ridit	29.7	95.5	44.7	139.2	44.9	114.3	—	—	39.8	116.3	34.2
Turkey	21.5	80.5	51.1	138.0	34.7	99.6	—	—	35.8	106.0	32.8
Triplet	31.6	102.4	39.0	124.5	40.7	102.0	—	—	37.1	107.6	34.0
Jenkin	31.5	95.5	32.1	132.2	—	—	36.8	98.6	—	—	—
Mosida	30.0	105.0	39.2	124.4	41.1	104.7	—	—	36.8	111.4	33.7
Albit	17.5	75.2	30.1	107.7	52.0	106.0	—	—	33.2	96.3	33.4
Hard Federation	—	—	35.6	78.5	—	—	39.8	92.2	—	—	—
Vernal (emmer)	—	—	53.9	120.4	—	—	—	—	—	—	—
White Polish	—	—	53.4	133.8	—	—	—	—	—	—	—
Kubanka (durum)	—	—	49.6	143.1	—	—	—	—	—	—	—
Onas	—	—	—	—	—	—	32.8	83.6	—	—	—
Little Club	—	—	—	—	—	—	34.6	87.4	—	—	—
Red Russian	—	—	—	—	44.8	125.8	—	—	—	—	—
White Winter	—	—	—	—	37.1	118.5	—	—	—	—	—

*Only fall-sown data of 1933 included.

The average for all varieties was 6.0 cm. The range in 1932 was from 4.25 cm in Hard Federation to 9.0 in Baart, and the average for all varieties was 7.0 cm. The range in 1933 in the fall-sown varieties was from 4.25 cm in Turkey to 6.25 cm in Ridit and Albit, with an average for all varieties of 5.5 cm. The maximum daily elongation for the spring-sown varieties was 5.5 cm in Little Club and 19.5 cm in Baart, with an average for all of 6.25 cm. These data show the need of frequent examination of varieties during the heading period if reliable comparative data on dates of heading are to be obtained.

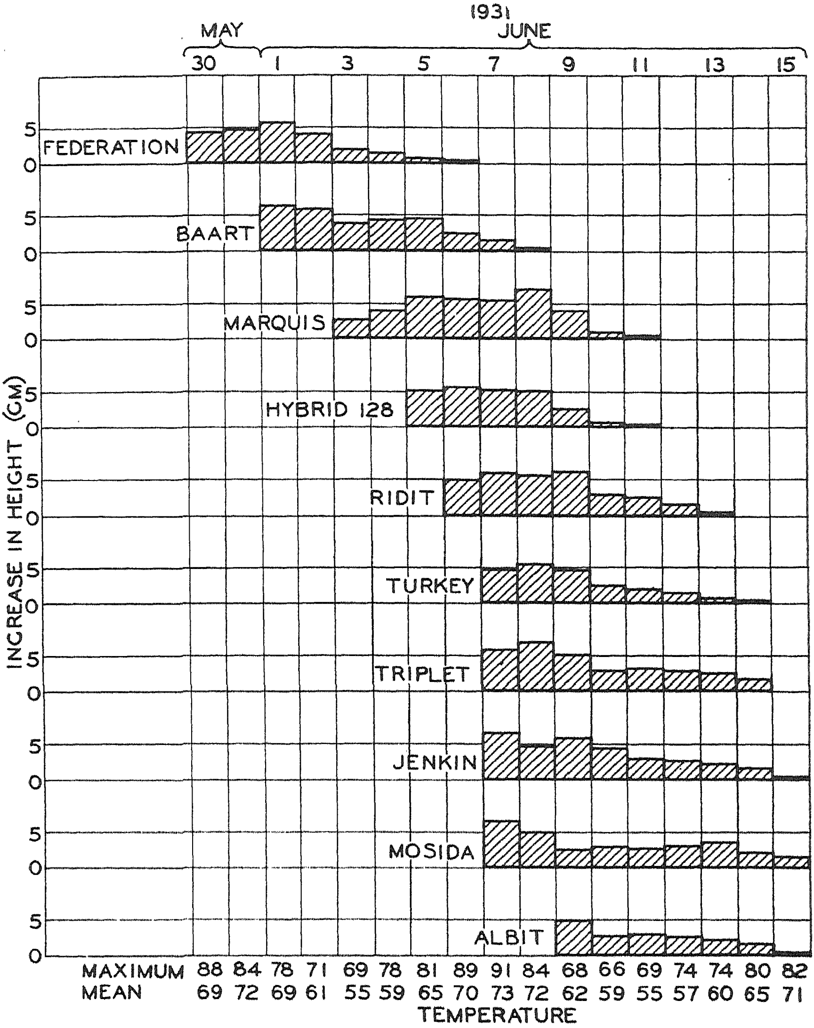

FIG. 1.—Daily increase in height of wheat varieties during the heading period in 1931.

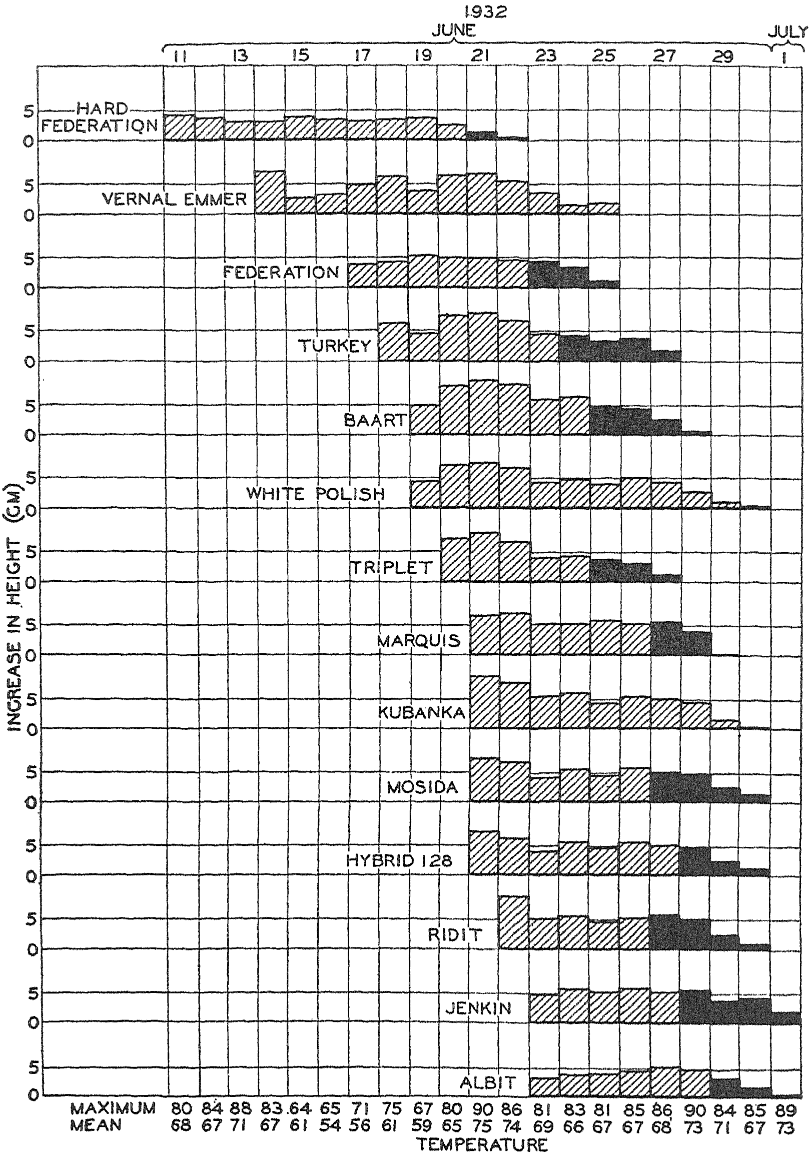

Fig. 2.—Daily increase in height and period of blooming of wheat varieties during the heading period in 1932. The blooming period is shown by solid black.

In general, the greatest increases in height of culm during heading were recorded for the tallest varieties, as shown in Table 1. The similarity in the 3-year average increase in height, expressed as a percentage of the total height as given in the last column of the table,

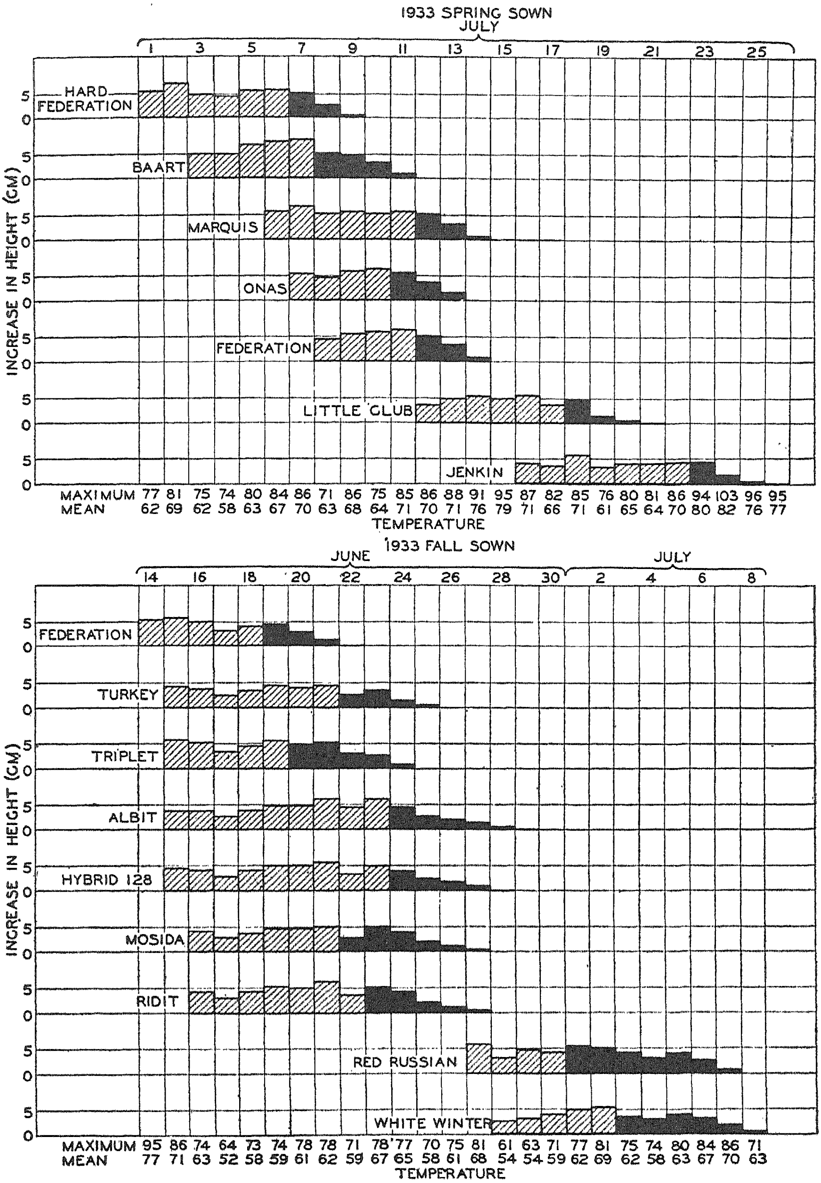

FIG. 3.—Daily increase in height and period of blooming of wheat varieties during the heading period in 1933. The blooming period is shown by solid black.

suggests an almost perfect correlation between plant height and increases in height during this period of growth. There are variations in the different seasons, but these seem unimportant in the light of this relation.

In recent years there has been considerable interest in growth curves and the possible relation of these curves to adaptation. Klages (1),[3] in a study of the growth of cereals and flax contemporaneous with the first 2 years of the present study, measured height at weekly intervals from emergence to the attainment of the maximum height of the plants. He believed that the analysis of growth curves might yield information of considerable value in evaluating yield data in field plat experiments.

The daily cumulative increases in the height of 10 varieties of wheat after first heading in 1931 are presented in the curves shown in Fig. 4.

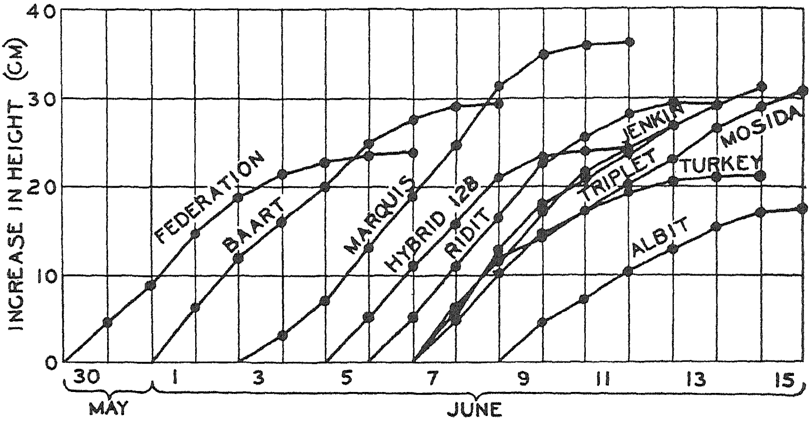

FIG. 4.—Daily cumulative increase in the height of culm from first heading to termination of growth in 10 varieties of wheat in 1931.

It is difficult to see in these curves any definite relation between type of growth and adaptation, except in so far as the form of the curve is affected by the final height of the plant. Thus, Jenkin, Triplet, Mosida, Federation, and Albit, which may be regarded as high yielding and well adapted, appear to differ in no material respect from Turkey, Marquis, and Baart, which are less well adapted. The results obtained in 1932 and 1933 lead to the same conclusion, so the growth curves for these years are not shown. There is some indication that the type of curve of the better adapted varieties shows the least fluctuation from season to season, but the significance of this relation, if any, must be verified by further experimentation.

EXSERTION OF THE SPIKE

Data on the exsertion of the spike from the sheath were obtained to determine the time required for the completion of the process. This information should be useful in making general observations on wheat at heading time. Daily measurements from the time the tip of the spike reached the upper ligule until the entire spike was exserted were made in 1932 and 1933.

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[3] Figures in parenthesis refer to "Literature Cited," p. 964.

Exsertion was completed in 2 to 4 days in the common wheats having spikes 6 to 10 cm in length, and in 1 to 3 days in the club varieties Hybrid 128, Albit, Jenkin, and Little Club. The latter have comparatively short spikes, averaging about 4 to 6 cm in length, and the spikes were visible through the open side of the sheath from 1 to 3 days before they reached the upper ligule. The spike of the durum variety Kubanka, about 8 cm in length, came out in 1½ days, while nearly 4 days were required for exsertion of the extremely long (15.7 cm) spike of White Polish. The most rapid exsertion occurred on warm days.

Table 2 shows the extent of exsertion of the tip of the spike above the ligule in 17 varieties of wheat. The total exsertion is highly correlated with the height of the plant. This is to be expected in the light of the data already presented and the fact that, on the average, the portion above the ligule comprises from 20 to 30% of the total height of the wheat plant.

TABLE 2.—*Total exsertion of the tip of the spike above the ligule in 17 varieties of wheat in 1931, 1932, and 1933.*

Variety	Spike exsertion, cm				Per cent of total height	Av. height of culm, cm	Length of spike, cm	
	1931	1932	1933	Av.			1932	1933
Federation	14.7	30.5	22.8	22.7	25.9	85.7	9.6	8.1
Baart	21.6	41.8	34.0*	32.5	30.1	107.8	9.4	8.1
Marquis	26.7	38.1	34.8*	33.2	30.4	109.3	10.7	8.9
Hybrid 128	17.5	39.1	28.2	28.3	26.3	107.8	4.8	4.3
Ridit	23.8	39.2	37.3	33.4	28.7	116.3	10.9	7.9
Turkey	16.0	41.4	27.7	28.4	26.8	106.0	9.6	6.6
Triplet	22.6	32.0	32.8	29.1	26.6	109.6	9.4	8.6
Jenkin	24.8	33.5	20.3*	26.2	24.1	108.8	6.4	5.3
Mosida	20.0	34.3	34.1	29.5	26.5	111.4	9.9	7.6
Albit	12.9	23.3	23.3	19.8	20.6	96.3	5.1	4.8
Hard Federation	—	—	31.2*	—	—	—	—	7.6
White Polish	—	42.1	—	—	—	—	15.7	—
Kubanka	—	42.3	—	—	—	—	7.9	—
Red Russian	—	—	35.0	—	—	—	—	7.9
White Winter	—	—	29.5	—	—	—	—	8.6
Onas	—	—	24.3*	—	—	—	—	7.1
Federation	—	—	24.6*	—	—	—	—	7.9
Little Club	—	—	21.1*	—	—	—	—	5.1

*Spring-sown; others fall-sown.

GROWTH DURING BLOOMING

Vegetative growth decreases and soon terminates after the blooming period begins, as the plant then turns its energies toward the production of seed, but in these studies some growth occurred after first blooming in all varieties. The average length of, and the increase in the height of the culm during the blooming period are shown in Table 3. The emmer, durum, and Polish varieties are not included because very few of their anthers were extruded. In 1932 a rather limited growth occurred during the period of blooming in Hard Federation,

Federation, and Albit. In the other varieties the increase in length of culm during this period ranged from 8.0 cm in Triplet to 13.3 cm in Ridit. The blooming period ranged from 1.1 to 3.5 days.

In 1933, in the fall-sown wheats, the increase in height during blooming ranged from 8.4 to 14.9 cm in the early and medium early varieties. In the late varieties, Red Russian and White Winter, the increase was 24.4 and 20.8 cm, respectively. In the spring-sown varieties the increase ranged from 6.2 to 13.8 cm. By brushing away the anthers from each spike daily in 1933 it was found that elongation of the culm apparently continued until the end of the blooming period even to the last spikelet. Blossoming after termination of growth was observed in only 2 of the 249 spikes examined.

The length of the blooming period in individual spikes in 1933 ranged from 3.3 to 6.3 days in the fall-sown wheats and from 2.8 to 4.1 days in the spring-sown varieties. This may be compared with a total blooming period of 10 days for all four spikes of an individual plant of Triplet and 17 days in another plant of the same variety having six spikes. The blooming period was extended considerably by the late secondary culms.

The percentage of the total height represented by growth after first blooming ranged from 2.2 in Hard Federation to 9.6 in Ridit in 1932. In 1933 the range was from 6.7% in Hard Federation to 19.4% in Red Russian.

The rapid decrease in the elongation of the culm at flowering time observed in Hard Federation both in 1932 and 1933 agrees in general with the results of Van de Sande-Bakhuyzen and Alsberg (4) and Van de Sande-Bakhuyzen (3), who found that in this same variety of wheat grown under constant conditions, the growth in length was lessened or stopped at the time of flowering or first fertilization. On the other hand, considerable growth of culm after flowering occurred in most other varieties. Slowing down of growth during flowering was found by Van de Sande-Bakhuyzen and Alsberg to be associated with a minimum relative increase in both the wet and dry weight of the plant, which occurred at the time of flowering. The results of Pope (2), in growth studies of barley, differed somewhat from those of the other investigators mentioned. He found that the leaf length began to taper off rapidly in Tennessee Winter barley when first flowering occurred, and the increase in height at the tip of the awn tapered off 5 days later. In Hannchen barley the leaf height tapered off much more slowly after first flowering and the awn tip height continued to increase rapidly for 10 days. Pope states that, "One factor contributing to this difference (between wheat and barley) may be that wheat flowers at a later stage of elongation than does barley."

SUMMARY

Daily measurements were made of the increase in the height of the plants at the tip of the spike and the ligule of the upper leaf during the heading period of 18 varieties of winter and spring wheat grown at Moscow, Idaho, during one or more of the 3 years, 1931 to 1933, inclusive.

TABLE 3.—*Time of blooming and increase in height during the blooming period in 15 varieties of wheat in 1932 and 1933.*

Variety	1932					1933				
	Date of first bloom	Number of days blooming	Height of culm			Date of first bloom	Number of days blooming	Height of culm		
			Total, cm	Increase during blooming				Total, cm	Increase during blooming	
				Actual, cm	Percentage of total				Actual, cm	Percentage of total
Fall-sown										
Hard Federation	June 21	1.1	78.5	1.7	2.2	June —	—	—	—	—
Federation......	June 24	2.1	101.3	5.5	5.4	June 19	3.3	76.7	8.4	11.0
Turkey........	June 25	3.5	138.0	11.0	8.0	June 22	3.3	99.6	7.7	7.7
Baart..........	June 25	3.1	129.0	11.7	9.1	June —	—	—	—	—
Triplet.........	June 25	2.6	124.5	8.0	6.4	June 20	4.6	102.1	14.5	14.2
Marquis........	June 26	2.6	126.4	10.1	8.0	June —	—	—	—	—
Mosida........	June 27	3.1	124.4	9.4	7.6	June 22	5.1	104.6	14.9	14.2
Hybrid 128.....	June 28	2.9	132.8	10.8	8.1	June 23	4.4	111.5	12.6	11.3
Ridit..........	June 27	3.2	139.2	13.3	9.6	June 22	4.6	114.3	14.4	12.6
Jenkin.........	June 29	3.3	132.2	12.5	9.5	June —	—	—	—	—
Albit...........	June 30	2.8	107.7	4.4	4.1	June 24	5.9	105.9	12.5	11.8
Red Russian....	—	—	—	—	—	July 2	6.3	125.7	24.4	19.4
White Winter...	—	—	—	—	—	July 2	6.0	118.6	20.8	17.5
Spring-sown										
Hard Federation	—	—	—	—	—	July 7	2.8	92.2	6.2	6.7
Baart..........	—	—	—	—	—	July 8	3.6	106.7	11.5	10.8
Marquis........	—	—	—	—	—	July 11	3.3	107.7	13.1	12.2
Onas...........	—	—	—	—	—	July 11	2.9	83.6	10.5	12.6
Federation......	—	—	—	—	—	July 12	2.8	89.9	8.0	8.9
Little Club.....	—	—	—	—	—	July 16	4.1	87.4	13.8	15.8
Jenkin.........	—	—	—	—	—	July 21	3.9	98.6	12.8	12.8

Wheat culms elongated rapidly during the heading stage, the rate of elongation increasing with the temperature. The maximum daily elongation during the heading period of varieties of common and club wheat ranged from 4.3 to 9.1 cm.

The average increase in the height of the culm after the tip of the heads emerged above the ligule in the common and club wheats was 30.6% of the final height of the plants in 1931, 35.6% in 1932, and 39.4% in 1933. No significant varietal differences were observed except those clearly associated with the final height of the plant. The culm continued to elongate for 5 to 12 days after the tip of the head emerged above the ligule.

No consistent relations were found between increase in height after heading, final height, exsertion of the head, or type of growth curve on the one hand and adaptation on the other. There were some indications that the amount of growth during the heading stage was less variable from season to season in the better adapted varieties, but this observation needs further verification.

The time required for the spike to exsert its full length from the boot was 2 to 4 days in the common wheats, 1 to 3 days in the short-spiked club varieties, and nearly 4 days in White Polish wheat, which has very long spikes.

Elongation of the wheat culm continued as long as blossoming continued and little or no growth occurred after blossoming was completed. The average blooming period for individual culms of the wheat varieties ranged from 1 to 3 days in 1932 and from 3 to 6 days in 1933.

LITERATURE CITED

1. KLAGES, K. H. W. The value and application of growth curves to field plat experiments. Jour. Amer. Soc. Agron., 25: 453–464. 1933.
2. POPE, M. N. The growth curve in barley. Jour. Agr. Res., 44: 323–341. 1932.
3. VAN DE SANDE-BAKHUYZEN, H. L. Studies upon wheat grown under constant conditions. Plant Physiol., 3: 1–30. 1928.
4. ———— and ALSBERG, C. L. The growth curve in annual plants. Physiol. Rev., 7: 151–187. 1927.

STUDIES ON BLOOMING IN RICE[1]

C. ROY ADAIR[2]

The blooming of five varieties of rice (*Oryza sativa*) was studied at Stuttgart, Ark., during the period of 1931 to 1933, inclusive, to obtain fundamental information necessary for successful hybridization, on the number of days required for all flowers on a panicle to bloom, the number of flowers that bloomed each hour on individual panicles, general weather conditions and hourly temperatures, percentage of relative humidity, and the time that pollen was liberated from the anthers.

Jones,[3] reviewing the literature on time of blooming, concludes that cultivated rice varieties may bloom between 6 a. m. and 4 p. m. The time of most active blooming seems to depend upon atmospheric conditions and the variety of rice. Rice appears to bloom earlier in the day in tropical rice-growing countries than it does in temperate regions. Jones[4] found in California that over three-fourths of the observed rice flowers bloomed between 12 noon and 2 p. m., and that more flowers bloomed between 2 and 4 p. m. than between 10 a. m. and 12 noon. Varietal differences appeared to have some influence on the time of blooming.

Laude and Stansel[5], in Texas, report that rice flowers bloomed between 8 a. m. and 4 p. m., the maximum number blooming between 11 a. m. and 12 noon. Most of the flowers on individual panicles completed blooming within 6 or 7 days, and the maximum number bloomed on the second and third days. They also found that the rate of blooming was positively correlated with the rate of vegetative growth.

MATERIAL AND METHODS

The blooming of Colusa, Early Blue Rose, and Fortuna was studied in 1931, and Caloro, Early Blue Rose, and Edith in 1932 and 1933. In 1931 observations were made on 11 and in 1932 and 1933 on 10 panicles of each variety. A total of 11,500 flowers was observed during the course of these studies.

Colusa and Caloro are early and midseason short-grain varieties and have small culms and narrow leaves. Early Blue Rose is an early-maturing, medium-grain variety that has heavy culms and fairly wide leaves. Edith and Fortuna are early- and late-maturing, long-grain varieties with large culms and wide leaves.

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[1] Cooperative investigations between Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the State Agricultural Experiment Station of the University of Arkansas. Received for publication August 13, 1934.

[2] Junior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry.

[3] JONES, JENKIN W. Review of the literature on pollination, hour of blooming, and natural crossing in rice. U. S. D. A. Bur. Plant Ind., Div. Cereal Crops and Dis. [Unnumbered Pub.], pp. 1–13. (Mimeographed.) 1929.

[4] JONES, JENKIN W. Observations on time of blooming of rice flowers. Jour. Amer. Soc. Agron., 16: 665–670. 1924.

[5] Laude, H. H., and Stansel, R. H. Time and rate of blooming in rice. Jour. Amer. Soc. Agron., 19: 781–787. 1927.

Each hour from 8 a. m. until 4 p. m., the flowers that had bloomed were counted and clipped from the panicles. Within a variety the flowers of the various panicles did not start to bloom on the same day. The number of flowers that bloomed on each panicle was recorded separately, and the average number of days required for all flowers of each variety to bloom was obtained.

Hourly temperatures were taken from thermograph charts at the station, and during the blooming period of 1932 the percentage of relative humidity was determined with a sling psychrometer.

BLOOMING PERIOD IN DAYS

The day of blooming and the percentage of flowers that bloomed each day during the 3-year period 1931–33 are shown in Table 1.

In 1931, the rate of blooming for Colusa and Fortuna was most rapid from the second to the fifth days. The maximum number for Fortuna was on the second day and for Colusa on the third day.

In 1932 and 1933 the rate of blooming for Caloro was very rapid from the second to the fourth days, and the maximum number in both years bloomed on the third day.

During the 3-year period the rate of blooming for Early Blue Rose was most rapid from the second to the third days in 1932 and from the second to the fourth days in 1931 and 1933. In 1932, Early Blue Rose began to bloom earlier and continued to bloom later in the day than in the other 2 years.

In 1932 and 1933 the rate of blooming for Edith was most rapid during the first 4 days.

Differences in the length of the blooming period and the hour of blooming appear to be due to varietal and climatic conditions. The blooming of Fortuna and Caloro was completed in a much shorter time than that of Colusa, Early Blue Rose, and Edith. Fortuna and Caloro also bloomed for a shorter time each day than did the other varieties. Edith differed from other varieties in that a much higher percentage of the flowers bloomed the first day. In Fig. 1 is shown the percentage of the total number of flowers of five varieties that bloomed each day during the 3-year period.

An average of nearly 10% of the total number of flowers bloomed on the first day and about 26% on the second day; about 79% during the first 4 days, and nearly 92% during the first 5 days of the blooming period.

HOURS OF BLOOMING

The hours of blooming and the number and average percentage of flowers that bloomed during the 3-year period of 1931–33 are shown in Table 2.

In 1931, Fortuna began to bloom before 10 a. m., but Colusa did not bloom until after that hour. The maximum number of flowers of Fortuna bloomed between 10 and 11 a. m. and of Colusa between 11 a. m. and 12 noon.

In 1932, Caloro began to bloom after 10 a. m. and in 1933 before that hour. In both years, the maximum number of flowers bloomed between 11 a. m. and 12 noon.

TABLE 1.—*Days of blooming and percentage of rice flowers that bloomed each day during the 3-year period, 1931–33.*

Day of blooming	Colusa, 1931	Fortuna, 1931	Caloro		Early Blue Rose			Edith		Average per-centage	Total number
			1932	1933	1931	1932	1933	1932	1933		
1st	8.68	7.71	4.56	8.65	8.69	7.95	7.74	19.83	17.06	9.72	1,118
2nd	16.30	28.24	24.32	27.34	23.33	28.56	22.99	30.89	26.09	25.64	2,949
3rd	24.96	22.66	28.29	30.42	23.76	22.46	24.83	17.15	23.63	24.30	2,794
4th	22.27	21.29	24.66	20.39	22.91	9.24	17.46	14.67	16.90	19.20	2,208
5th	17.59	15.00	11.40	9.96	12.20	15.06	11.72	9.61	7.63	12.29	1,413
6th	6.56	4.97	5.32	3.24	5.74	10.81	9.73	3.41	6.32	6.15	707
7th	2.69	0.14	1.44	—	2.74	4.25	4.35	3.41	1.97	2.05	236
8th	0.94	—	—	—	1.19	1.48	1.03	0.83	0.41	0.59	68
9th	0.01	—	—	—	—	0.18	0.15	0.10	—	0.05	6
10th	—	—	—	—	—	—	—	0.10	—	0.01	1
Number of flowers studied	854	2.114	1,184	1,295	1,427	1,082	1,357	968	1,219	—	11,500
First day of blooming	Aug. 13	Sept. 10	Aug. 21	Aug. 18	Aug. 18	Aug. 17	Aug. 11	Aug. 17	Aug. 11	—	—
Average length of blooming period, days	7.18	6.18	6.90	5.70	7.50	7.80	7.60	7.70	7.50	—	7.12

TABLE 2.—*Hours of blooming and number and average percentage of flowers that bloomed during the 3-year period, 1931–33.*

Hours	Colusa, 1931	Fortuna, 1931	Caloro		Early Blue Rose			Edith		Total	
			1932	1933	1931	1932	1933	1932	1933	Number	%
Before 9 a.m.	0	0	0	0	0	17	1	2	11	31	0.27
9 to 10 a.m.	0	69	0	4	23	4	16	9	119	244	2.12
10 to 11 a.m.	28	1,463	70	40	289	145	390	132	733	3,290	28.61
11 a.m. to 12 noon	499	571	881	776	420	142	691	332	265	4,577	39.80
12 noon to 1 p.m.	256	11	224	465	632	472	227	368	86	2,741	23.83
1 to 2 p.m.	52	0	9	10	63	194	32	102	4	466	4.05
2 to 3 p.m.	19	0	0	0	0	95	0	19	1	134	1.17
3 to 4 p.m.	0	0	0	0	0	13	0	4	0	17	0.15
Total	854	2,114	1,184	1,295	1,427	1,082	1,357	968	1,219	11,500	

None of the flowers of Early Blue Rose bloomed before 9 a. m. in 1931, but as many as 17 bloomed before that hour in 1932. In 1931 and 1933, blooming was completed by 2 p. m.; however, in 1932, 108 flowers bloomed after that hour. In 1931 and 1932, the maximum number of flowers bloomed from 12 noon to 1 p. m., whereas in 1933 the maximum number bloomed between 11 a. m. and 12 noon.

The vegetative growth of the varieties was more vigorous and they headed earlier and in a shorter time in 1933 than in 1932. The more vigorous growth no doubt accounted in part for blooming at an earlier hour and at a more rapid rate in 1933 than in 1932. In Fig. 2 is shown the percentage of the total flowers of five varieties of rice that bloomed each hour during the 3-year period.

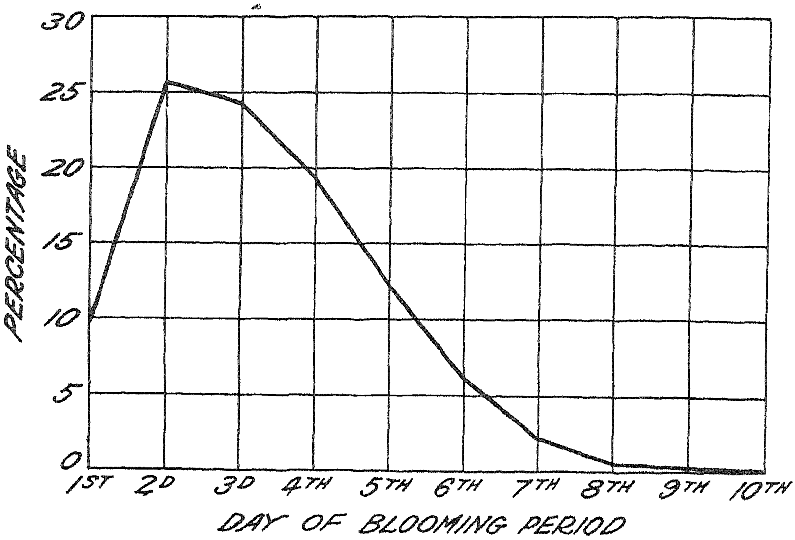

FIG. 1.—Percentage of total flowers of five varieties of rice that bloomed each day during the 3-year period, 1931–33.

An average of less than 2.5% of the total number of flowers bloomed before 10 a. m. and less than 1.5% after 2 p. m. An average of nearly 29% of the total number of flowers bloomed between 10 and 11 a. m., 40% between 11 a. m. and 12 noon, and over 92% between 10 a. m. and 1 p. m.

EFFECT OF TEMPERATURE

Atmospheric temperature probably is the most important factor influencing the blooming of rice. The maximum temperatures were much higher and the minimum temperatures lower in 1932 than in 1933, but the temperatures early in the morning were higher in 1933 than in 1932. The maximum rate of blooming for Early Blue Rose and Edith was earlier in the day when the temperatures in the morning were high and both varieties bloomed later in the day when the temperatures were low. Owing to the high temperatures in 1932 some flowers probably bloomed late in the day that would not have bloomed until the following day had the temperatures been lower. Early Blue Rose develops slowly under a wide range in temperature The inability of this variety to develop at a normal rate when the days are hot and the nights cool makes it undesirable for late seeding.

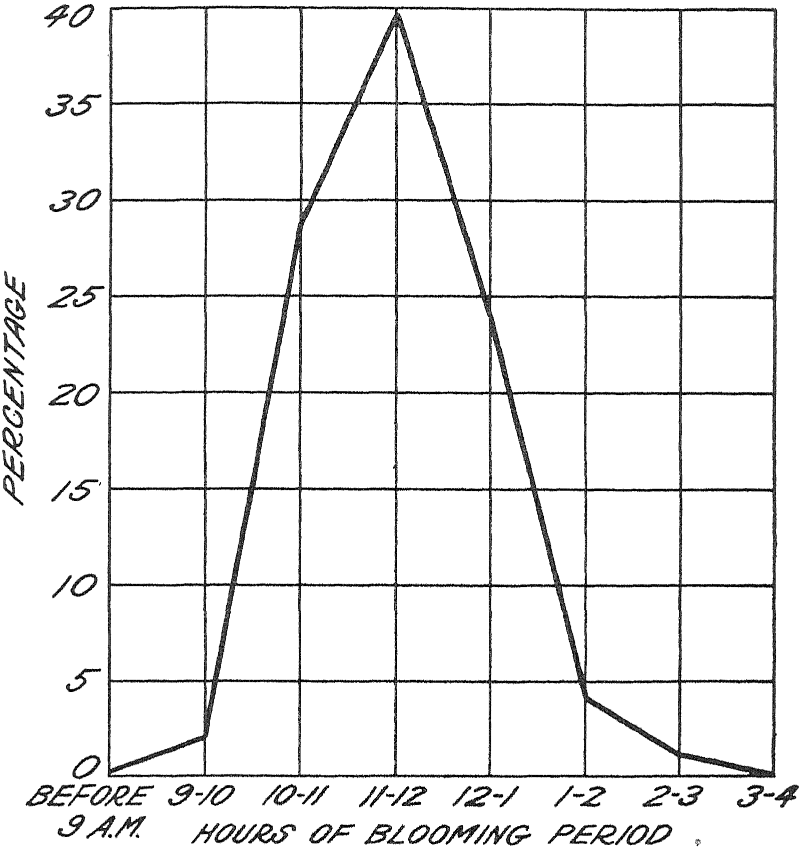

FIG. 2.—Percentage of the total number of flowers of five varieties of rice that bloomed each hour during the 3-year period, 1931–33.

In 1932 and 1933, temperatures during the period of blooming of Caloro were not so different as were those during the blooming period of the earlier varieties. The optimum temperature for rapid blooming prevailed earlier in the day in 1932 than in 1933 and more flowers of Caloro bloomed after 12 noon in 1933 than in 1932. With higher afternoon temperatures in 1932 the number of Caloro flowers that bloomed did not increase as did those of Early Blue Rose and Edith. This may be regarded as a varietal difference affecting rate and hour of blooming.

The number of flowers that bloomed each hour for days having marked differences in range of temperature shows clearly the effect of temperature on the time of blooming.

The hourly temperatures and the number of flowers of Colusa and Fortuna that bloomed each hour during 2-day periods in 1931 are shown in Table 3. Both varieties began to bloom earlier on days when the morning temperatures were high and the maximum rate of blooming also was earlier in the day when high temperatures occurred at an early hour. Colusa and Fortuna did not start to bloom until the temperatures reached about 80° and 88° F, respectively.

TABLE 3.—*Hourly temperatures and the number of Colusa and Fortuna flowers that bloomed each hour during a 2-day period in 1931.*

Hour	Temperature, °F		No. Colusa flowers that bloomed		Temperature, °F		No. Fortuna flowers that bloomed	
	Aug. 13	Aug. 14	Aug. 13	Aug. 14	Sept. 13	Sept. 14	Sept. 13	Sept. 14
9 a.m.	72	74	—	—	80	84	—	—
10 a.m.	77	79	—	—	84	90	—	32
11 a.m.	79	81	—	3	88	91	94	323
12 noon	80	83	4	45	90	94	328	3
1 p.m.	81	84	16	63	91	94	3	1
2 p.m.	83	83	40	9	92	96	—	—
3 p.m.	82	84	11	8	91	96	—	—
4 p.m.	82	84	—	—	90	96	—	—

In Table 4 are shown the hourly temperatures and the number of flowers of Caloro that bloomed each hour during 2-day periods in 1932 and 1933. All florets bloomed between 10 a. m. and 1 p. m. and blooming was most active between 11 a. m. and 12 noon, when the temperature ranged from 89° to 98° F. On August 26, 1932, and August 20, 1933, the sky in the morning was clear and temperatures were high, but increasing cloudiness in the afternoon appears to have caused a slowing down in the rate of blooming. On August 27, 1932, and August 22, 1933, the sky was clear all day. The temperature rose slowly until afternoon when it remained quite uniform.

TABLE 4.—*Hourly temperatures and number of flowers of Caloro that bloomed each hour during 2-day periods in 1932 and 1933.*

Hour	1932				1933			
	Temperature, °F		No. flowers that bloomed		Temperature, °F		No. flowers that bloomed	
	Aug. 26	Aug. 27	Aug. 26	Aug. 27	Aug. 20	Aug. 22	Aug. 20	Aug. 22
10 a.m.	92	89	—	—	86	85	—	—
11 a.m.	95	92	3	1	89	87	5	1
12 noon	98	95	213	13	90	89	375	25
1 p.m.	99	92	10	81	90	90	40	153
2 p.m.	100	93	—	—	90	90	—	—

TABLE 5.—*Hourly temperatures and number of flowers of Early Blue Rose that bloomed each hour during 2-day periods in 1931, 1932, and 1933.*

Hour	1931				1932				1933			
	Temperature, °F		No. flowers that bloomed		Temperature, °F		No. flowers that bloomed		Temperature, °F		No. flowers that bloomed	
	Aug. 19	Aug. 20	Aug. 19	Aug. 20	Aug. 21	Aug. 22	Aug. 21	Aug. 22	Aug. 13	Aug. 14	Aug. 13	Aug. 14
8 a.m.	74	72	—	—	72	76	—	—	73	80	—	—
9 a.m.	76	77	—	—	77	84	—	13	76	83	—	1
10 a.m.	81	80	—	23	80	88	—	2	79	82	3	2
11 a.m.	76	82	—	260	84	89	4	121	82	83	34	184
12 noon	76	85	228	57	87	93	5	17	84	86	209	102
1 p.m.	80	86	24	1	89	94	52	18	86	88	37	41
2 p.m.	79	86	11	—	90	95	51	4	87	74	1	1
3 p.m.	82	85	—	—	92	93	18	—	88	68	—	—
4 p.m.	83	85	—	—	90	90	2	—	—	—	—	—

In Table 5 are shown the temperature and the number of flowers of Early Blue Rose that bloomed during 2-day periods in 1931, 1932, and 1933. Each year the flowers started to bloom earlier in the day when the morning temperatures were high. August 21, 1932, was a rather cool, clear day and blooming started late and continued until late in the afternoon, whereas the next morning was clear and very warm, but the afternoon was cloudy and blooming started early in the morning but ceased soon after the sky became cloudy.

In Table 6 are shown the temperatures and the number of flowers of Edith that bloomed each hour during 2-day periods in 1932 and 1933. August 21, 1932, was a cool, clear day and blooming started late in the morning and continued until late in the afternoon, whereas on the following day blooming started at 9 a. m., when the temperature reached 84°, and ceased early in the afternoon. On August 12 and 13, 1933, the sky was cloudy early in the morning but clear for most of each day. The temperatures were much higher on August 12 than on August 13, and the flowers began to bloom earlier and ceased blooming earlier on August 12.

TABLE 6.—*Hourly temperatures and the number of Edith flowers that bloomed each hour during 2-day periods in 1932 and 1933.*

Hour	1932				1933			
	Temperature, °F		No. flowers that bloomed		Temperature, °F		No. flowers that bloomed	
	Aug. 21	Aug. 22	Aug. 21	Aug. 22	Aug. 12	Aug. 13	Aug. 12	Aug. 13
8 a.m.	72	76	—	—	81	73	—	—
9 a.m.	77	84	—	1	85	76	11	—
10 a.m.	80	88	—	1	88	79	30	30
11 a.m.	84	89	1	100	91	82	236	222
12 noon	87	93	56	12	93	84	33	38
1 p.m.	89	94	53	3	93	86	—	1
2 p.m.	90	95	41	2	88	87	—	—
3 p.m.	92	93	3	—	74	88	—	—
4 p.m.	90	90	—	—	72	88	—	—

These results indicate that the rate and hour of blooming of rice flowers are governed to a large extent by the temperature and by the intensity of the sunlight. In all cases blooming started early in the morning when the temperatures were high and the sky was clear, but blooming ceased or materially slowed down when the sky became cloudy and the temperatures dropped. On comparatively cool, clear days the flowers started to bloom late in the morning and continued to bloom slowly until rather late in the afternoon.

The data presented in Tables 3, 4, 5, and 6 show that rice flowers start to bloom at lower temperatures in certain years than they do in others. The temperature at which blooming starts depends somewhat upon the range of temperatures that prevail during the blooming period. Flowers of late-maturing varieties and varieties sown late will bloom when the temperature is very low, but under such conditions very few seeds are set because apparently very little functional pollen is produced.

EFFECT OF HUMIDITY

The percentage of relative humidity was determined each hour during the day for the period covered by these studies and the number of flowers that bloomed on single panicles on definite days was observed. On certain days both Early Blue Rose and Edith continued to bloom much later in the day when the humidity was low than when it was high, but Caloro continued to bloom later in the day when the humidity was high. Apparently the intensity of the sunlight and the temperature have a much more important effect on the rate and hour of blooming than does the percentage of relative humidity.

TIME OF DEHISCENCE

All varieties studied shed their pollen just before or at the time the flowers opened.

SUMMARY

The number of days required for the blooming of all flowers on a panicle and the hour of blooming appear to depend primarily upon the variety, the atmospheric temperature, the intensity of sunlight, and probably other climatic conditions.

The blooming of Fortuna and Caloro was completed in fewer days and over a shorter period each day than that of Colusa, Early Blue Rose, and Edith. Edith bloomed at a faster rate the first day than did the other varieties.

The rate of blooming was most rapid during the first 4 days of the blooming period, and the maximum number of flowers bloomed on the second or third day.

None of the flowers observed bloomed before 8 a. m. or after 4 p. m., and the maximum rate of blooming was between 10 a. m. and 1 p. m., being very fast at about 12 noon, except for Fortuna in 1931 and Edith in 1933. Uniform temperatures were conducive to a rapid rate of blooming. With high afternoon temperatures the number of Caloro flowers that bloomed did not increase as did those of Early Blue Rose and Edith. Blooming started early in the day when the temperatures were high and materially slowed down when the sky became cloudy and the temperature dropped. On cool, clear days the flowers started to bloom late in the morning and continued to bloom until rather late in the afternoon. Late in the fall, rice flowers often bloom at low temperatures but set very few seeds.

Most varieties started and stopped blooming earlier in the day when the humidity was high than when it was low; however, the effect of humidity was not so marked as that of temperature.

Pollen was shed just before or at the time the flowers opened.

THE EFFECT UPON YIELD OF CUTTING SWEET CLOVER (*MELILOTUS ALBA*) AT DIFFERENT TIMES AND AT DIFFERENT HEIGHTS[1]

R. J. Garber, M. M. Hoover, and L. S. Bennett[2]

In the late spring of 1931, 65 contiguous plats, each measuring 6 by 6 feet and surrounded by an alley 18 inches wide, were staked out in a sweet clover field on the agronomy farm of the West Virginia Agricultural Experiment Station. Thirteen different cultural treatments including the check were planned. Four treatments and the check were arranged in the form of a Latin square. These treatments consisted of cutting the sweet clover at different dates in 1931, the same year the crop was seeded. The other eight treatments occurred on an adjacent area 61.5 by 39 feet, each treatment being represented by five plats distributed at random. On this area the treatments consisted of cutting the sweet clover at different heights and at different stages of growth the second year after seeding.

In Table 1 are shown the data obtained from the Latin square arrangement. Beginning with August 1, 1931, the sweet clover on five plats was cut at an approximate height of 6 inches with an ordinary hand sickle at each cutting date mentioned in column 1. In columns 2 and 3 the average approximate height of plants on May 25 and June 30, 1932, are shown.

TABLE 1.—*Effect upon height and yield of cutting sweet clover the first year of its growth.*

Date cut in 1931	Average height, inches		Average yield of dry hay, grams (less than 1% moisture)		
	May 25	June 30	1931	1932	Total
(1)	(2)	(3)	(4)	(5)	(6)
Not cut.......	27.4	49.2	——	1,912	1,912
Aug. 1.........	23.2	44.6	919	1,571	2,490
Aug. 20.......	20.8	45.2	1,121	1,542	2,663
Sept. 10......	20.4	44.6	1,190	1,385	2,575
Sept. 30......	19.4	43.0	1,095	1,370	2,465

It is apparent that the plants on the five plats not cut during the first season averaged somewhat taller than the others; also that the range in average heights taken on May 25 was slightly greater than that of the later measurements. The plants on the untreated plats showed a more vigorous growth during the entire season of 1932. This condition was also reflected by the stand of weeds. Buckhorn, major plantain, sheep sorrel, and white top were present in plats cut on September 10 and September 30 but were entirely absent in the plats that were not cut the first season.

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[1] Contribution from the Department of Agronomy and Genetics, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director as Scientific Paper No. 139. Received for publication September 5, 1934.

[2] Head of Department, formerly Associate Agronomist, and Instructor, respectively.

In columns 4, 5, and 6 the average yields of dry hay may be found. The analysis of variance in yields obtained in 1932 as well as of total yields show the differences due to treatment to be significant. The standard error for the average yield of five plats in 1932 was 63.5 grams, whereas for total yields it was 81.3 grams. In 1932 the average yield from the untreated plats was significantly greater than the average yield from the others. The average yields in 1932 from the plats cut the previous year on September 10 and September 30 were probably significantly less than those cut August 1 and August 20. Among total average yields there was probably no significant difference except that the plats not cut the first season yielded less than those that were cut at that time.

In Table 2 are shown the data obtained from cutting sweet clover at different heights and different stages during the second year of growth. This feature of the experiment was planned in order to answer certain questions in regard to handling the crop when grown as a cover in orchards. In columns 1, 2, and 3 the stage of development, the approximate height at which the plants were cut, and the date harvested may be found. The average height of the plants when harvested and the average yield of dry hay in grams are shown in columns 4 and 5. Under remarks (column 6) notes relative to seed production appear.

The stage at which the plants were cut is indicated by the name of the treatment as well as by the average height of the plants when harvested. The "pre-bud" cutting was made late in May before the flower buds appeared. About a month later when the first flower buds began to open, the plants were considered in the "early bloom" stage, and on July 11 they were considered in "full bloom."

The average heights when harvested (column 4) show that the plants cut in the "pre-bud" stage at 12 inches made a somewhat more vigorous recovery than those cut at 6 inches. This is also reflected in the average yields of the second cutting, *viz.*, 576 grams as compared with 459 grams (column 5), even though the plants representing the former were cut 6 inches higher. The difference between the average yields of the first cutting of these two treatments may largely be attributed to the difference in the height of the stubble. One of the yields of the first cutting for the plats cut at 12 inches was recorded abnormally low and hence was discarded. The average heights of the plants when harvested at "early bloom" and "full bloom" were similar. The plants on the plats harvested at both "pre-bud and early bloom" averaged 25.2 and 15.6 inches high, respectively, when cut. The greatest average yields were obtained from the plants in the "full bloom" stage. The difference between the average yields of plants cut at 6 inches in "full bloom" and "early bloom" is approximately 2.4 times its standard error. In no case did the average yield of plants cut twice equal that of plants cut but once in the "full bloom" stage. The differences in average yields of the 6-inch and 12-inch cuttings were of the order expected. It will be noticed that there are 10 plats in the "pre-bud and early bloom" treatment. Originally it was planned to cut five of these plats a third time, but since the plants died after the second cutting, the yields of the 10 plats were averaged.

TABLE 2.—*Effect upon height, yield, and seed production of cutting sweet clover the second year of its growth.*

Stage cut in 1932	Approximate height of stubble, inches	Date harvested	Average height when harvested, inches	Weight of dry hay, grams (less than 1% moisture)	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
Pre-bud and full bloom..	6	May 25; July 26	25.8–21.5	1,099.4+459*	1 plat saved for seed
Pre-bud and full bloom..	12	May 25; July 26	26.5–28.4	807.5*+576*	1 plat saved for seed
Early bloom............	6	June 24	48	1,699	2 plats produced few seed; 3 plats produced no seed
Early bloom............	12	June 24	49	1,443	2 plats produced ample seed; 2 plats produced few seed; 1 plat produced no seed
Full bloom.............	6	July 11	51.2	1,905	No seed produced; plants dead
Full bloom.............	12	July 11	49.8	1,857	No seed produced; plants dead
Pre-bud and early bloom.	6	May 25; July 11	25.2–15.6	1,049.3†+340.5†	No seed produced; plants dead

*Average based on 4 plats.
†Average based on 10 plats.

The rank growth usually obtained with sweet clover is objectionable in orchards, but it is desirable to permit the plants to produce sufficient seed to re-establish the crop. For this reason the question of seed production after second season plants are cut is an important one. It is obvious from Table 2, column 6, and from other data not reported here that plants cut once only and in the "pre-bud" stage may be depended upon to produce adequate seed. A few of the plants cut at a height of 6 inches in the "early bloom" stage produced some seed, whereas those cut at a height of 12 inches in the same stage of growth produced considerably more seed. Of the five plats so treated two produced ample seed, two few seed, and one plat produced no seed at all. Results similar to those mentioned in this paragraph were obtained from a preliminary experiment established in 1930 but not described in this paper.

The germination of seed produced on plants previously cut was found to be as good as that produced on plants not previously cut. Samples of 100 seeds each from uncut plants germinated (germination plus hard seed) 92%, 89%, and 97%; from plants cut at 6 inches in "pre-bud," the seed germinated 94%, 95%, and 82%. Additional germination tests were made and similar results obtained.

CONCLUSION

Biennial sweet clover (*Melilotus alba*) cut the same year it is seeded reduces somewhat the yield of dry hay of the second year's crop, although the total yield is greater from plants cut both the first and second year. Weeds are more likely to be troublesome if sweet clover is cut the same season it is seeded.

Plants cut the second season at the "pre-bud" stage of growth make a somewhat more vigorous recovery than when cut later; also plants cut at a height of 12 inches are damaged somewhat less than when cut at 6 inches.

Plants cut in "pre-bud" may be depended upon to produce ample seed for re-establishing the crop, whereas plants cut later may or may not produce sufficient seed, depending somewhat upon the season. Seed harvested from plants previously cut germinated as well as seed from comparable plants not previously cut.

STEM MAGGOT INJURY AMONG WHEAT VARIETIES[1]

R. S. DUNHAM[2]

The injury to wheat from the wheat stem maggot (*Meromyza Americana* Fitch) has become increasingly serious during the last 5 years in northwestern Minnesota. Counts of the dead spikes in random samples from the wheat varietal plats have been made at the Northwest Experiment Station, Crookston, Minnesota. An analysis of these data to determine any varietal difference in susceptibility to the attacks of this insect is presented in this paper.

Host resistance to insect attack is a well-known fact among entomologists and there is a growing belief in the importance of breeding crop plants resistant to particular insect pests. Selection of particular varieties or species of food plants by certain insects has been attributed to differences in odor, taste, or some attribute of a plant less evident to human senses (2).[3] Workers at the Kansas Experiment Station have reported evidence of resistance to Hessian fly injury as a characteristic of some varieties of winter wheats (3), while Parker and Painter (4) have mentioned briefly some of the more important studies on host resistance in crop plants.

Very little information concerning the behavior of wheat varieties to stem maggot attack, however, appears in the literature. Gilbertson (1) observed that the beardless varieties were attacked less than the bearded, although all beardless varieties did not show equal resistance.

EXPERIMENTAL RESULTS

In Table 1 the average percentages of dead spikes caused by the wheat stem maggot are shown for nine varieties over a period of 4 years. The data are averages of two random samples of 100 culms each from each of three 1/40 acre plats planted the same day on uniform soil. Dates of heading are also presented in order to study any association of maximum injury with early or late maturity.

It will be noted that there is considerable variation from year to year among the varieties in the extent of injury. Thus, Reward, an early heading variety, was not as severely injured in 1929 and 1933 as some other varieties but was severely injured in 1931 and 1932. McColloch (2) believes that "every species of insect prefers an optimum condition of the host which it selects and will choose a new host in the optimum condition in preference to an old host in which the conditions are unfavorable."

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[2] Agronomist and Assistant Professor, Northwest School of Agriculture, Crookston, Minn. Assistance in analysis of the data by Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, and Dr. F. R. Immer, Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, is gratefully acknowledged.

[3] Reference by number is to "Literature Cited," p. 980.

TABLE 1.—*Percentage of dead spikes in nine wheat varieties caused by stem maggot. 1929 amd 1931–33.*

Variety	Minn. No.	1929		1931		1932		1933		4-year average	
		Dead spikes	Date headed	Dead spikes	Date headed	Dead spikes	Date headed	Dead spikes	Date headed	Dead spikes	Date headed
Supreme........	2309	5.7	July 14	6.3	June 30	8.3	June 22	6.0	June 29	6.57	July 1
Reliance........	2221	5.2	July 14	5.3	July 1	11.0	June 24	7.7	June 29	7.30	July 2
Mindum........	470	4.2	July 15	7.7	June 30	13.3	June 24	5.3	June 29	7.62	July 2
Thatcher.......	2303	4.2	July 10	7.3	June 28	16.0	June 23	7.7	June 26	8.80	June 29
Reward.........	2204	3.7	July 7	10.7	June 25	17.3	June 18	4.3	June 22	9.00	June 25
Ceres...........	2223	3.7	July 14	4.0	June 28	11.0	June 23	4.3	June 29	5.75	June 28
Marquillo.......	2202	3.2	July 13	10.7	June 28	9.3	June 20	6.0	June 27	7.30	June 29
Marquis........	1239	2.7	July 15	8.7	June 30	10.7	June 24	5.3	June 30	6.85	July 2
Hope...........	2297	2.5	July 16	6.3	June 30	8.7	June 24	4.7	June 29	5.55	July 2
Average......		3.9		7.4		11.7		5.7		7.19	

To determine whether the varieties differed significantly in the percentage of dead spikes, the data were analyzed by the analysis of variance method. In this analysis the data from each of the three plats for each of the 4 years were used, making a total of 108 plats. The results are shown in Table 2.

TABLE 2.—*Analysis of data by analysis of variance method.*

Variation due to	D/F	Sums of squares	Mean squares	Z	5% point
Years	3	918.08	306.03	1.8578	.5055
Varieties	8	136.05	17.01	.4128	.3677
Varieties x years	24	296.40	12.35	.2528	.2628
Blocks	8	77.34	9.67	—	—
Error	64	476.99	7.45	—	—
Total	107	1904.86	—	—	—

From this analysis it may be noted that the odds are greater than 19:1 that the varieties differ significantly in the extent of their injury. The odds are nearly 19:1 that the varieties did not react in the same manner in different years.

By extracting the square root of the mean square for error, 7.45, we obtain the S.D. of a single determination and as there were 12 plats in all, the standard error of the mean difference between two varieties for the 4-year period is $\sqrt{7.45}\ \sqrt{2}/\sqrt{12}$ or 1.11. Varieties that differ in average injury by a percentage of 2.22 give odds of 19:1 of being significantly different in maggot injury. Reward with an average percentage of dead spikes at 9.00 and Hope with an infection percentage of 5.55 differ by 3.45 or more than 3 times the standard error of a difference. Subtracting 2.22 from 9.00 gives 6.78 and from 8.80 gives 6.58 and on this basis one may conclude that the chances are 39:1 that both Reward and Thatcher are more susceptible than Supreme, Ceres, or Hope.

LITERATURE CITED

1. GILBERTSON, G. I. The wheat stem maggot. S. Dak. Agr. Exp. Sta. Bul. 217. 1925.
2. MCCOLLOCH, J. W. The resistance of plants to insect injury. Bien. Rpt. Kan. State Hort. Soc., 37:196–208. 1924.
3. PAINTER, R. H., SALMON, S. C., and PARKER, J. H. Resistance of varieties of winter wheat to Hessian fly. Kans. Agr. Exp. Sta. Tech. Bul. 27. 1931.
4. PARKER, J. H., and PAINTER, R. H. Insect resistance in crop plants. Sixth Int Cong. Gen. Proc., 2:150–152. 1932.

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THE RESPONSIBILITIES OF AGRONOMISTS[1]

R. I. THROCKMORTON[2]

At this time, when the so-called evils of overproduction are being discussed, it seems appropriate to inquire into the responsibilities of agronomists. Agronomists are frequently given the credit of having been too successful in increasing production through the introduction and development of new varieties of crops and the improvement of some of the older varieties and through better soil management practices that are the result of soil research. It has been said rather frequently, during the last three or four years, that the agronomists have taken their task of making two blades of grass grow where one grew before too seriously, and actually made three and even four blades grow where one grew before. It has also been said that too many men have been trained for scientific work in agronomy. Again the statement is sometimes made that the country will soon have a planned or regimented agriculture, and there will then be no place for the men engaged in research in crop production, plant breeding, soil chemistry, soil biology, soil management, and other technical branches of agronomy. Strange as it may seem some of these accusations have come from men who are engaged in agronomic work. However, the majority of the men who are devoting their efforts to research in soils and crops are more far sighted and have more vision and believe that developments of the last few years have increased their opportunities for service and their responsibilities to society. We should, however, ask ourselves if we have been too zealous, if we have been too ardent in our devotion to our chosen field of endeavor, and if we have encouraged too many men to prepare themselves for scientific work in this field.

At a time like the present, it is obvious that it is wise to look forward as well as backward, and that in looking backward the clouds of the last four years must not be permitted to dim the vision. Since this Society was organized, great advances have been made in training men for teaching and research in agronomy. As a result of this training, the science has advanced rapidly and has had a tremendous influence on the economic and social life of the nation. That it will continue to have an equal or greater influence cannot be doubted.

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[1] Presidential address delivered before the twenty-seventh annual meeting of the Society held in Washington, D. C., November 22, 1934.

[2] Head of Department of Agronomy, Kansas State College, Manhattan, Kansas.

The last three or four years have been years of an increase rather than a decrease in the demand for information from agronomists. Never before have soil and crop investigators been called upon to supply as much or as varied information as during these years. There has not been a great surplus of well-trained agronomists during this period. It is true that in some cases individuals could not find employment to their liking, but on the other hand it has been rather difficult at times during the last year to locate men who are adapted for certain types of agronomic work.

The present adjustment programs may be taken as an indication of the reorganization that must take place in the agriculture of the country. Never before have the people as a whole been so thoroughly aroused as to the condition of agriculture as they are at the present time. The popular idea that agriculture could keep on growing and expanding of its own momentum has been largely dispersed. It is now generally realized that the period of expansion is practically over and that millions of acres of land that have been used in the past for the production of cultivated crops can no longer be used economically for this purpose. Something must and will be done with this land to restore its productivity so it will become available later for crop production if and when it is needed, or it will be seeded to pasture crops or planted to trees. In the final analysis, the best use that can be made of it will be determined by the crops and soils men of the country who are engaged in research work. The problems that this land is presenting at the present time are almost without number, although it has received the serious thought of research men in agronomy for only a very short period of time.

Many practical agronomic problems that are demanding immediate attention have arisen during the last few months as a result of the present agricultural program. It is to the credit of the soils and crops men that the fundamental research necessary to answer many of these problems had already been conducted and the answers were available. However, the answer is not available for many of the other problems and will not be until after much time and effort have been devoted to research. It seems that it may take many years and the efforts of many scientists to solve some of these problems, many of which appear to be more difficult than most of those with which agronomic scientists have been working for the last two or three decades.

As the agriculture of the country becomes older and is more definitely and more permanently organized, the acreage used for the production of cultivated crops may be expected to decline gradually. This does not mean that there will be less need for agronomic research, but that the need for such research will increase. As the acreage used for the production of a crop is reduced, it becomes necessary to make the production of that crop more stable on the remaining acres. The wide fluctuations which exist in the total production of each of several of the important crops today should not be permitted to occur in the future. Fluctuations in crop yields cannot be prevented, but the plant breeder, the crops production man, and the soil scientist working together can do much to help stabilize production.

If the country should have regimented agriculture it will become more necessary than ever before that each farmer, individually, receive the maximum returns from the acres in cultivation. It will be more difficult, if not impossible, for him to overcome low yields per acre by materially increasing the acreage. It will be necessary, for the welfare of both the individual farmer and the country, that production be more stable and efficient.

Whether the agriculture of the country becomes definitely organized, regimented, or more stabilized through education, it seems that the scientists in the various fields of research in soils and crops are facing a period of increased activity and responsibility.

In addition to the heavy responsibility which agronomists have in supplying through research the technical information that is needed for the development of a sound agriculture, they also have the responsibility of training the men who will be the scientists of the future in this field. This responsibility is not only to the men who are being trained, but to society as a whole.

It may well be asked if this responsibility has been fully met in the past and if it is being met successfully at this time. Is it not true that too many men are being trained purely as plant breeders, or as specialists in plant breeding in one particular crop, that too many men are being trained in only one line of crop production, and that too many men are being trained too narrowly as soil chemists or soil biologists? Are the men who have been trained in some phase of agronomy during the last few years and those who are being trained today too narrow in their viewpoint? Can they see the entire field of agriculture or are they so deeply imbedded in their own narrow field that they fail to see the relationships of their work to the science of soils and of crop plants or its relationships to the welfare of society?

The scientists in agronomy should be true scholars, men of learning who have a broad vision and who can see the field of agriculture as a whole. The educational trend of today, however, tends to produce men of skill and of high specific knowledge. Technical skill in working with plants or soils in the field, greenhouse, and laboratory is essential, but it is not enough. The agronomist must have not only skill in his technical field, but he must also have an eager and questioning mind if he is to be responsive to his obligations. He must also be able to appreciate and understand the relation of his problems and of his findings to the entire field of agriculture. The man who is intensively trained in a narrow field, regardless of how important that field may be, will not, unless he is an exceptional human being, be able to see the broader aspects of the results of his research to society.

Specialization during the student's undergraduate days should be discouraged. He should be encouraged to pursue a relatively broad course in agriculture and to secure good training in the sciences that are basic to agriculture and in the social sciences. The young man who enters college with the idea that he is going to be a plant breeder, a soil biologist, a soil chemist, or a scientist in any one of several other specialized fields is often impatient to begin work in his chosen field. It is frequently difficult to persuade these impatient, ambitious young men that it is necessary for them first to build a firm foundation on the basic sciences before they can hope to go very far in the field in which they think they are so vitally interested. In such cases, an early awakening to the importance of strong fundamental training, in which the relation of the basic sciences to the specialized technical field is clearly pictured, is essential. It is also important that these men be given a clear understanding and appreciation of the relationships between the special scientific branches of agriculture in which they are interested and all other branches of agriculture. For example, the young man who expects to devote his life to the improvement, development, or production of some of the forage crops should first understand the feed requirements of livestock. He should have a good general knowledge of animal nutrition if he is to understand the application of the results of his research in the animal industries.

It is not uncommon in this day of intensive specialization for an undergraduate to request permission to substitute some course in his special field of interest or a course closely related to it for some required course in agriculture or one of the related fields. Too frequently, these requests are granted and the student does not get a well-balanced training in agriculture and consequently his vision is limited and he cannot progress as far as he should. He frequently has difficulty in applying the result of his research because he cannot understand its broader relationships. He may also find it difficult to cooperate with the research workers in other branches of agriculture because he does not have the broad training to enable him to understand and appreciate their viewpoint.

If agronomists are to be developed who can successfully meet the problems of the future, it will be necessary during their undergraduate days to do more than insist upon good training in the basic sciences and in agriculture. These men must be taught the importance of cooperating with other scientists and they must be helped to understand how to work with others and to be tolerant of their ideas. This spirit and attitude must be developed during the undergraduate days, while the student's mind and reaction may be more readily molded to such a pattern. The spirit of cooperation has always been important but is rapidly becoming more essential in agronomic research. As more attention is given to fundamental research in agronomy the problems become more closely related to other sciences and the cooperation of men in these related fields is necessary for their solution.

With this type of undergraduate training, the future agronomist will have a good foundation in the basic sciences and in agriculture at the time he starts his graduate work. He will be ready to develop the skill and technic that are necessary in his specialized field. During the first part of the period of graduate study, however, the student must not be permitted to limit his studies to a field that is too narrow, because conditions or opportunities may lead him into some related line of work. This is especially important for the man who is striving only for the master's degree.

During the period of graduate study, the student must be helped to develop the personal qualities that are essential to success in his field. Honesty to his research and to himself is important while he is pursuing his studies but becomes even more important when he is placed in charge of a project or research problem. Willingness to recognize the contributions of co-workers and to give unselfishly credit to subordinates, are personal qualities that must frequently be developed. There is a natural tendency for men in research to be selfish. This is not surprising because the individual who has worked upon a project for several years and who may have had several assistants during that time gradually comes to look upon the project and the results from it as a part of his life. It is only natural that he should wish to receive credit for his work and he should have it, but he must also give credit to others if he is to become known as one who develops research men. An effort should also be made during the period of graduate training to impress upon the student the folly of "rushing into print" with the results of his studies. Premature publication is dangerous and may place the investigator in an embarrassing position. If the importance of postponing publication until there is no doubt as to the soundness of the conclusions reached or as to the value of the results is firmly impressed upon the graduate student, he will not be likely to err in this regard in later years.

If the science of agronomy is to maintain the high standard it has had in the past, greater care must be used in selecting the men who are to be encouraged to do graduate work. At times it is difficult to prevent men of only average ability from continuing their studies and striving for a master's degree or even a doctorate. Such men, however, should be discouraged, especially when they wish to secure an advanced degree merely as a means of aiding them in securing a position in the technical field. The men who receive financial aid from an institution in the form of assistantships, fellowships, or scholarships should be selected with great care. If men of only average ability and promise are selected for these positions, they may keep more worthy men from doing graduate work. Even more important than this factor, is the influence that such men may have on the standing of agronomic research. A large number of men with advanced degrees in agronomy who cannot find employment, because of their low native ability or because of their lack of adaptation for research, would tend to place the entire field of agronomy on a lower plane and make it more difficult for the well-trained men who have the personal qualities necessary for successful research work to secure satisfactory employment or remuneration. It is much more to the credit of an institution or an individual who is engaged in research or teaching to have a few students who become outstanding in their work, than to have many students who are mediocre. As a means of safeguarding the future, only those young men of high native ability, high scholastic attainment, and good basic training who have a true interest in agronomic research should be encouraged or assisted to do graduate work.

THE RELATION BETWEEN TOTAL CALCIUM AND PHOSPHORUS IN MATURE PRAIRIE GRASS AND AVAILABLE PLANT FOOD IN THE SOIL[1]

HARLEY A. DANIEL AND HORACE J. HARPER[2]

Information concerning those factors which affect the mineral composition of forage is important since the growth of animals may be retarded when fed on hay or allowed to graze on grasses which are deficient in certain elements, particularly phosphorus and calcium. Studies on the mineral deficiency in pasture plants have been conducted by various investigators (1, 2, 7, 8, 11),[3] and they have found that the total calcium and phosphorus content of plants was slightly correlated with the available minerals in the soil. Studies on the composition of cultivated crops produced on soils varying in available plant food content have been made by Holtz (9), Hartwell (6), Shedd (12), and others, and they also have found that the available minerals in the soil were correlated with the calcium and phosphorus content of the crops which were grown. Blair and Prince (3) state that the phosphorus content of the soil had little or no influence on the composition of soybeans, since one soil containing 0.1% P_2O_5 produced plants with about the same phosphorus content as another soil which contained eight times as much total phosphorus.

More than one-half of the total acreage of hay and the major portion of the pastures in central and eastern Oklahoma are composed of *Andropogon furcatus* or *scoparius*. Many of the soils on which these grasses grow are also low in available phosphorus and frequently are medium to strongly acid, consequently a study of the mineral composition of grasses and the available plant food in the soil on which they are found is important in order to secure more information in regard to correlation which may exist between the ash analysis of the plant and mineral deficiencies in the soil.

EXPERIMENTAL PROCEDURE

Composite samples of mature blue stem grasses (*Andropogon furcatus* and *scoparius*) were collected each fall from 1929 to 1933, inclusive, from typical areas of pasture land, from hay meadows, and from virgin soils in 37 counties in Oklahoma. During this period 66 samples of grass were collected. A sample of surface soil was secured from each area where grass samples were harvested. Sixty-two samples of soil were collected for analysis. In a few instances samples of big and little blue stem grass were secured from the same area of land and this will explain why there were four more samples of grass than soil.

The plants were dried at 105° C to remove moisture and were analyzed for total calcium and phosphorus by official methods recommended by the American Association of Official Agricultural Chem-

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[2] Assistant Agronomist and Professor of Soils, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 992.

ists. The easily soluble phosphorus in the soil was determined by extracting the soil with N/5 sulfuric acid (5). The hydrogen-ion concentration of the soil was determined electrometrically, using the quinhydrone electrode. The procedure for base exchange calcium was as follows: 10 grams of the pulverized soil were treated with 200 cc of a normal solution of neutral ammonium acetate to a temperature of 30° to 35° C. After intermittent shaking for 30 minutes the suspensions were filtered and calcium was determined by official methods, using 150 cc of the clear filtrate.

CALCIUM AND PHOSPHORUS CONTENT OF GRASS AND AVAILABLE PLANT FOOD IN SOIL

Data on the total calcium and the phosphorus content of mature grass and the acidity, exchangeable calcium, and easily soluble phosphorus in the soil are shown in Table 1. These results indicate that the species of Andropogons studied are adapted to a wide range of soil conditions. The easily soluble phosphorus content of these soils ranged from 3 to 170 p. p. m. The exchangeable calcium varied in percentage from 0.037 to 0.830. The highest acidity as measured by the hydrogen-ion concentration was pH 5.3, and the highest alkalinity was pH 9.2.

Apparently these grasses require very little available plant food for growth, since 33 of these soils contained less than 10 p. p. m. of easily soluble phosphorus, 19 samples had a pH content of 6.0 or less, and more than half of the soils were also very low in exchangeable calcium.

The total mineral content of the grasses was quite variable. The quantity of total calcium in the plants varied from 0.100 to 0.638%, and the average or mean of the 66 samples was 0.2704 ± .0014%. Occasionally, a sample of grass may be obtained from an area where soil moisture conditions are very favorable for plant development and the phosphorus content of this sample will be higher than the average. Sample 58 was collected from an alluvial soil where moisture conditions were favorable for growth during the growing season and this sample contained 0.191% of total phosphorus which is more than twice as much phosphorus as usually occurs in the average sample of upland prairie hay.

A more detailed study of the mineral deficiency in native grasses, which is being made at the present time, indicates that soil moisture conditions as affected by drought or excessive rainfall produce a marked effect on the phosphorus content of grass. Samples Nos. 13, 14, 31, and 35 collected from areas of residual soil in southwestern Oklahoma which were high in available phosphorus were very low in total phosphorus. These grass samples were collected following a period of prolonged drought which is a common occurrence in that section of the state. Samples Nos. 27 and 63 were obtained from central and eastern Oklahoma where the total annual rainfall is from 35 to 45 inches. The easily soluble mineral phosphate in the soils from which these samples were secured was only 5 p. p. m., although the plants contained 0.109 and 0.111% of total phosphorus, respectively. More information is needed on the effect of organic phosphorus in soil and the effective rainfall in relation to the absorption of phosphorus by plants. This problem is being studied at the present time in this laboratory.

The correlation coefficients for total calcium and total phosphorus in the mature native grasses and the exchangeable calcium and the

TABLE 1.—*Data on the total calcium and phosphorus content of andropogon furcatus ans scoporius and the acidity, easily soluble phosphorus, and base exchange calcium in the soil.*

Sample No.	Composition of grass		Composition of soils		
	Total calcium %	Total phosphorus %	Base exchange calcium %	Easily soluble phosphorus p. p. m.	pH
			Andropogon furcatus		
1	0.161	0.041	0.229	12	9.2
2	0.380	0.059	0.248	18	7.3
3	0.136	0.104	0.301	170	8.0
4	0.467	0.120	0.547	90	8.5
5	0.264	0.065	0.104	6	6.3
6	0.638	0.112	0.606	24	8.2
7	0.402	0.081	0.328	7	5.8
8	0.171	0.126	0.076	14	6.5
9	0.195	0.047	0.117	9	6.5
10	0.100	0.045	0.114	8	6.1
11	0.330	0.078	0.122	6	6.3
12	0.174	0.072	0.066	5	7.1
13	0.328	0.055	0.107	80	8.6
14	0.268	0.051	0.121	50	7.2
15	0.270	0.067	0.037	5	5.8
			Andropogon scoparius		
16	0.207	0.078	0.088	8	5.7
17	0.244	0.072	0.137	12	6.8
18	0.405	0.076	0.312	5	6.1
19	0.221	0.067	0.130	18	6.1
20	0.105	0.069	0.098	36	6.4
21	0.225	0.055	0.045	12	6.9
22	0.190	0.072	0.038	20	6.6
23	0.185	0.097	0.127	24	7.1
24	0.343	0.055	0.122	7	6.0
25	0.360	0.043	0.082	4	6.1
26	0.283	0.051	0.102	7	5.6
27	0.228	0.111	0.066	5	7.1
28	0.148	0.042	0.145	18	7.1
29	0.200	0.072	0.096	16	7.3
30	0.271	0.058	0.104	8	8.0
31	0.265	0.054	0.110	40	7.3
32	0.115	0.055	0.070	8	7.3
33	0.184	0.073	0.226	24	7.3
34	0.402	0.061	0.830	8	8.7
35	0.325	0.038	0.107	80	8.6
36	0.186	0.096	0.158	40	6.8
37	0.170	0.076	0.190	64	7.6
38	0.218	0.069	0.121	50	7.2
39	0.408	0.109	0.180	130	7.8
40	0.241	0.078	0.148	38	7.0
41	0.176	0.104	0.223	36	7.0
42	0.179	0.087	0.183	22	6.8

TABLE 1.—*Concluded.*

Sample No.	Composition of grass		Composition of soils		
	Total calcium %	Total phosphorus %	Base exchange calcium %	Easily soluble phosphorus p. p. m.	pH
		Andropogon furcatus and *scoparius*			
43	0.272	0.100	0.122	12	6.1
44	0.408	0.070	0.083	5	5.3
45	0.333	0.094	0.178	3	6.4
46	0.358	0.066	0.101	6	5.6
47	0.331	0.076	0.067	4	6.6
48	0.223	0.072	0.083	7	6.0
49	0.262	0.056	0.097	9	6.0
50	0.293	0.088	0.138	3	6.0
51	0.325	0.060	0.143	6	5.9
52	0.439	0.074	0.529	30	6.8
53	0.392	0.077	0.137	10	6.3
54	0.317	0.052	0.104	7	5.8
55	0.257	0.054	0.105	4	5.5
56	0.500	0.069	0.165	6	5.8
57	0.194	0.068	0.107	8	5.5
58	0.285	0.191	0.212	75	6.4
59	0.138	0.083	0.145	20	6.4
60	0.200	0.044	0.155	4	6.1
61	0.224	0.083	0.122	12	7.4
62	0.200	0.057	0.136	10	5.9
63	0.270	0.109	0.037	5	5.6
64	0.279	0.053	0.104	4	5.8
65	0.290	0.071	0.105	5	5.8
66	0.287	0.076	0.074	6	5.6
Average or mean	.2704±.0084	.0740±.0020			
Standard deviation	.1015±.0059	.0250±.0014			

easily soluble phosphorus in the soil are shown in Table 2. A positive correlation of 0.50 ± .09 occurred between the exchangeable calcium in the soil and the total calcium in the grass. A correlation of 0.35 ± .11 was obtained between the easily soluble phosphorus in the soil and the total phosphorus in the plant. According to these calculations the composition of the soil is not closely associated with the composition of the plant, however mineral deficiencies in livestock are common in areas where the fertility of the soil is low due to the fact that the forage produced is low in calcium and phosphorus. Data on the nitrogen content of the soils and grasses are not included in this table as there was no relation between the nitrogen content of the soil and the total nitrogen in the grass. Studies on the soil reaction in relation to the total nitrogen in the plant did not indicate that the absorption of soil nitrogen by the grass was affected by soil reaction. The nitrogen content of grass grown in regions of low rainfall (25 inches annually) was also quite similar to the nitrogen content of the same species of grass grown in areas where the total rainfall was higher (40 inches annually).

TABLE 2.—*Correlation coefficients for the total calcium and phosphorus in mature Andropogon furcatus and scoparius and the exchangeable calcium and easily soluble phosphorus in the soil.*

No. of correlation	Kind of correlation	No. of samples	Base exchange calcium in soil and total calcium in plant	Easily soluble phosphorus in soil and total phosphorus in plants
1	All grass given in Table 1	66	0.50 ± .09	0.35 ± .11
2	Grasses grown on soils deficient in exchangeable calcium	50	0.068 ± .14	
3	Grasses grown on soils not deficient in exchangeable calcium	16	0.62 ± .15	
4	Grasses grown on soils deficient in easily soluble phosphorus	33		— .33 ± .16
5	Grasses grown on soils not deficient in easily soluble phosphorus	33		0.30 ± .16

In order to make a more detailed study of the correlation existing between the total minerals in the plant and the available minerals in the soil, the soils were divided into two groups, *viz.*, those deficient in calcium and phosphorus and those not deficient in these elements. Soils deficient or not deficient in phosphorus were separated according to recommendations made by Harper (5), who found that soil containing 10 p. p. m. or more of easily soluble phosphorus did not give any response to an application of phosphate fertilizer when planted to grain sorghums and that soils containing less than 10 p. p. m. of phosphorus soluble in a 1 to 10 extract using fifth normal sulfuric acid were deficient in this particular element.

Data presented by Comber (4) were used to separate the soils into two groups depending upon the amount of replaceable calcium which they contained. Since he found that one soil containing 0.155% of exchangeable calcium responded to an application of lime and another soil that contained 0.183% did not, it was assumed that any soil included in the study containing less than 0.170% of exchangeable calcium was deficient in calcium. The authors appreciate the fact that the ratio between total exchangeable bases in soil and exchangeable hydrogen is also an important factor in the nutrition of lime-loving plants, but it is doubtful if this factor is important in the case of grasses which will make an excellent growth on medium acid soils when other conditions are favorable.

Data on the correlation coefficients secured from the total calcium and phosphorus content of plants grown on soils deficient and not deficient in each of these available minerals are included in Table 2. These data indicate a slight positive correlation between the total calcium and phosphorus in the grass and the exchangeable calcium and easily soluble phosphorus in the soil when the plants were grown on soils that were not deficient in available minerals. A correlation of 0.62 ± .15 was found between the total calcium in the plant and soils not deficient in exchangeable calcium. A correlation of 0.30 ± .16 was secured between soils not deficient in easily soluble phosphorus and the total phosphorus in the plant.

A very poor correlation of 0.068 ± .14 was found between the total calcium in the grass and the exchangeable calcium in the soil when the plants were collected from soils containing less than 0.170% of exchangeable calcium. A negative correlation of — .33 ± .16 was found to exist between the total phosphorus in the grasses and the easily soluble phosphorus in the soil when those plants were grown on phosphorus-deficient soil that contained less than 10 p. p. m. of phosphorus soluble in fifth normal sulfuric acid.

Russell (10) states that the "absorption of nitrogen, phosphorus, and potassium is rapid in the earlier days of the plants life, but markedly falls off later so that the percentage of these substances in the dry matter decreases as growth proceeds. Absorption of calcium, on the other hand, continues and the percentage increases somewhat with the growth of the plant." In a study conducted in this laboratory on the nitrogen, phosphorus, and calcium content of prairie grass at different stages of growth, it was found that the nitrogen and phosphorus are high in the young plants and decrease toward maturity. The total calcium in the plants increases at first and then decreases at a slower rate than the phosphorus and nitrogen as the plant matures.

The results which have been obtained in this investigation indicate that there is no simple relation between the total quantity of any one element in the plant and the availability of that element in the soil. Climatic conditions affect the absorption of different ions and this phase of the problem will be presented in another paper. The effect of the antagonism between potassium and calcium and the disturbing influence of organic phosphates in soils which are high in organic matter undoubtedly account for a part of the lack of correlation which seems to occur in many instances.

SUMMARY

The chemical composition of 66 samples of *Andropogon furcatus* and *scoparius* and of 62 soils collected during a period of 4 years from 37 counties in Oklahoma were studied. The samples of grass were taken from typical areas of native pastures, hay meadows, and virgin soils. It was found that these grasses make a good growth on both acid and basic soils and often on soils very low in easily soluble phosphorus, base exchange calcium, and organic matter.

The correlation coefficient for the comparison between total calcium in the grass and the exchangeable calcium in the soil was 0.50 ±

.09 and the correlation between the available phosphorus in the soil and the total phosphorus in the grass was 0.35 ± .11.

It was found that a slight positive correlation existed between the total calcium in the plant and the exchangeable calcium in high calcium soils. No data were obtained that would indicate that plants growing in soil low in base exchange calcium would also be low in this element. A slight positive correlation occurred between the total phosphorus in the grass and the easily soluble phosphorus in the soils when the grasses were grown on soils high in easily soluble phosphorus. A slight negative correlation occurred when the plants were collected from soils containing less than 10 p. p. m. of available phosphorus.

The data presented indicate very clearly that a study of a single plant food element in soil will not give an accurate indication as to the amount of that element which will be found in the plant. The effect of soil moisture conditions during the growing period is a very important factor in increasing or retarding the intake of calcium and phosphorus from the soil. Further studies are being made on the effect of climatic conditions on the composition of forage.

LITERATURE CITED

1. Armstrong, S. F. The botanical and chemical composition of the herbage of pastures and meadows. Jour. Agr. Sci., 2: 283. 1907-08.
2. Aston, B. C. Mineral content of pastures. New Zealand Jour. Agr., 37: 242. 1928.
3. Blair, A. W., and Prince, A. L. The influence of phosphates on the phosphoric acid content of the plant. Jour. Agr. Res., 44: 579. 1932.
4. Comber, Norman M. Scientific Study of the Soil. New York: Longmans, Green, and Co. 1932. (Page 118.)
5. Harper, Horace J. Easy soluble phosphorus in Oklahoma soils. Okla. Agr. Exp. Sta. Bul. 205. 1932.
6. Hartwell, Burt L. The percentage of total phosphorus in flat turnips as influenced by the amount available in soils. R. I. Agr. Exp. Sta. Bul. 154. 1913.
7. Godden, William. Report on the chemical analysis of samples of pastures from various areas in the British Isles. Jour. Agr. Sci., 16: 78. 1926.
8. Guthrie, F. B. Notes on Osteo-malacia (bone chewing). New South Wales Dept. Agr. Sci. Bul. 12. 1914.
9. Holtz, Henry F. Effect of calcium and phosphorus content of various soil series in Western Washington upon the calcium and phosphorus composition of oats, red clover, and white clover. Wash. Agr. Exp. Sta. Bul. 243. 1930.
10. Russell, Edward J. Soil Conditions and Plant Growth. London: Longmans, Green, and Co. Ed. 6. 1932.
11. Scott, Samuel G. Phosphorus deficiency in forage feeds of range cattle. Jour. Agr. Res., 38: 113. 1929.
12. Shedd, O. M. Effect of certain calcium compounds and other substances on the yield and calcium content of some crops. Soil Science, 14: 233. 1922.

DETERMINING YIELDS ON EXPERIMENTAL PLATS BY THE SQUARE YARD METHOD[1]

C. A. MICHELS AND JOHN SCHWENDERMAN[2]

Under certain conditions it is sometimes necessary or desirable to determine yields on experimental plats by harvesting a number of very small apparently representative areas. Theoretically, harvesting and computing yields of the entire plats would be the most satisfactory way of determining yields. Under certain field conditions, however, it may be practically impossible to obtain accurate results from large plats. The lodging of grain and forage, the uneven stands due to winter killings, burning during the jointing stages of grain, unpreventable losses occurring during harvesting and threshing, and losses incident to weathering are some of the more serious difficulties met with when the entire plat is harvested. In carrying out cooperative demonstration work on grains or forage with farmers it is often desirable to use a number of square yards for computing yields from plats or fields. It is highly probable that some, if not all, of these difficulties can be eliminated by the use of a number of square yards for the determination of yields on large plats.

REVIEW OF LITERATURE

Arny and Garber (1),[3] working with fertilizers on cereals, conclude that nine rod rows from tenth-acre plats gave practically as accurate indications of the value of fertilizer treatments as did harvesting the product of the entire plats. The rod-row method may be used to advantage in determining yields of grain where facilities are lacking for harvesting and threshing accurately the products of the entire areas. Arny and Steinmetz (2), in a later study with fertilizer applications to cereals at University Farm and at eight sub-stations located in different parts of Minnesota, found that yields determined from four or five systematically distributed square yard areas removed from plats one-tenth acre in size or less, from a relatively uniform crop, may be confidently substituted for that from the entire plat. They also found that yields from uniform stands determined by 10 square-yard areas systematically distributed may not be as accurate as yields determined from entire plats.

Kiesselbach (3) studying the methods of eliminating experimental error in comparative crop tests found that the results from 20 systematically distributed quadrats may be safely substituted for the yield of the entire plat.

MATERIALS AND METHODS

Data from yields obtained on plats and by six square yards on varieties of winter and spring wheat, barley, and oats grown at University Farm, Moscow, Idaho, for the seasons of 1929, 1930, and 1931 furnish the basis for this investigation. The plats were 7 feet by 155.56 feet, 1/40 acre in area. Each plat was bordered on each side by an alley 2 feet wide. All plats were laid out with their long axis parallel to the apparent trend of soil heterogeneity. All the grain varieties were replicated systematically at least three times. Plats were seeded with a 7-foot 14-row drill which was calibrated to deliver a uniform amount of seed per unit area.

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[2] Assistant Agronomist and Major Student in Agronomy, respectively.

[2] Figures in parenthesis refer to "Literature Cited," p. 1001.

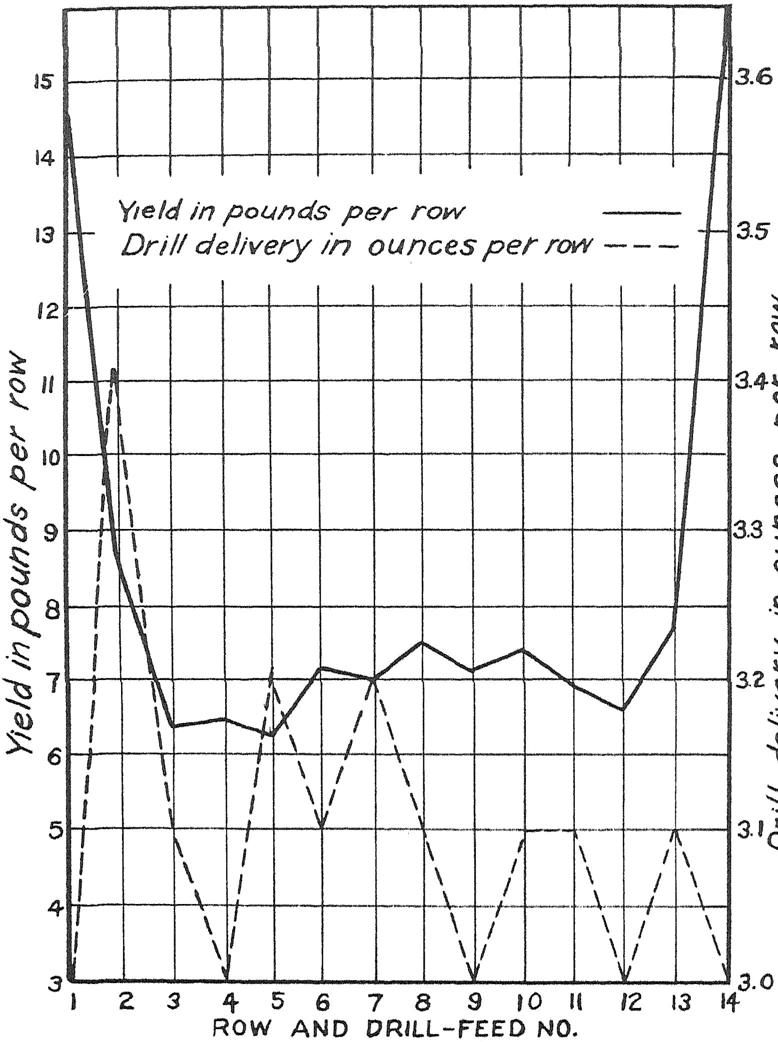

FIG. 1.—Yields and delivery rates of individual drill rows of White Odessa wheat for the season of 1926.

Fig. 1 illustrates actual grain delivery and yield per row. The rows in each plat were numbered from 1 to 14 from left to right. Rows 1 and 14 are designated as outside border rows, 2 and 13 as inside border rows, and the remaining 10 rows as the central 10 rows. In a previous study on cereals, Hulbert and Michels (4) found that alley space materially increased the yields on the outside border rows and to a less extent on the inside border rows, and that the true yielding ability of a variety can be obtained only by computing yields on the central 10 rows.

At harvest time the four border rows were removed by hand and six square yards were taken at random from each plat. The instrument for laying off the square yards consisted of a frame 36 x 36 inches with the fourth side open and was made out of channel iron with a face 1 inch wide and 1½ inches thick. The corners of the frame were reinforced on the outside to prevent the two free ends from spreading. The area removed within the frame included six drill rows each 3 feet long. In 1929 and 1930 all of the square yards were kept separate. Square yard bundles were properly labeled and wrapped in strong wrapping paper to prevent loss of grain by shattering. After the square yards were taken the plat was harvested with a grain binder.

The square yard grain bundles and those from the plats were threshed separately with a No. 1 Ellis-Keystone separator equipped with special devices for thorough cleaning of grain and prevention of losses. Yields per acre were computed on weight of grain from square yards. The weight of grain from square yards was added to the weight of grain of the plat before plat yields were computed.

An investigation of this kind extending over a period of 3 years entails the accumulation of a large amount of data, so for analysis and interpretation the data were reduced to a convenient form so that relevant information of the mass might be explained in terms of a few numerical and biometrical values. Summaries showing the relative yields between plat and square yards, together with their statistical constants, are presented in Table 1.

In Table 1, when the average yield of 56 barley plats for the season of 1929 is compared with average yield of their 336 square yards, the difference is 3.1 bushels in favor of the square yard method. The difference in yield between the mean of 135 plats of barley for the season of 1930 and the mean yield of their 810 square yards is 0.8 bushel in favor of square yards. In oats, for the season of 1929, the difference between the average of 81 plats and the average yield of their 486 square yards is 6.3 bushels, and in the season of 1930 the average of 80 plats yielded 2.4 bushels less than did the average yield of their 480 square yards. The difference between the average yield of 97 plats of spring wheat and the average yield of their 582 square yards for the season of 1929 is 2.5 bushels in favor of the square yard method. In 1930 the average yield of 94 spring wheat plats was 0.2 bushel more than the average yield of their 564 square yards.

In 1929, the average yield of 137 plats of winter wheat yielded 2.4 bushels less than did the average yield of their 822 square yards and in 1930 the average yield of 93 plats of winter wheat yielded 0.8 bushel less than did the average yield of their 558 square yards.

TABLE 1.—*Comparing the average plat yield of grain in bushels per acre of all the varieties of barley, oats, and wheat with their respective square yard yields of grain for the seasons of 1929 and 1930.*

Class	Year	No. of plats	No. of square yards	Means			Coefficient of variability			Correlation coefficient
				Plat, bu. per acre	Square yards, bu. per acre	Difference, bu.	Plat, bu. per acre	Square yards, bu. per acre	Difference, bu.	
Barley.	1929	56	336	36.7±0.1548	39.8±0.1451	3.1±0.2214	34.67±2.330	30.0 ±2.077	4.67±3.1213	0.981±0.0049
Barley.	1930	135	810	50.3±0.661	51.1±0.6677	.8±0.9431	22.72±0.980	22.42±0.9650	.3 ±1.3753	0.9317±0.0011
Oats...	1929	81	486	61.5±0.8472	67.8±0.7238	6.3±1.1142	18.11±0.990	15.49±0.841	2.62±1.2990	0.5755±0.0743
Oats...	1930	80	480	45.1±1.2363	47.5±1.2598	2.4±1.2600	34.69±2.064	38.78±2.359	4.09±3.1352	0.9526±0.007
Spring wheat	1929	97	582	41.4±1.1328	43.9±1.2681	2.5±1.1327	24.43±1.366	28.90±1.511	2.47±2.0368	0.8673±0.0252
Spring wheat	1930	94	564	28.0±0.3988	27.8±0.4065	0.2±0.5736	13.75±0.688	14.00±0.702	0.25±0.9830	0.9275±0.0097
Winter wheat	1929	137	822	44.8±0.7131	47.2±0.6678	2.4±0.9770	19.02±0.803	14.08±0.585	4.94±0.9935	0.8437±0.0246
Winter wheat	1930	93	558	44.1±0.5936	44.9±0.415	0.8±0.7252	12.9±0.649	12.76±0.652	0.14±0.9200	0.7446±0.046

The difference between the plat yields and square yard yields on all classes of grain for the season of 1929 is relatively high when compared with the deviations for the season of 1930, due to a seasonal condition. The total precipitation for this season was 10.63 inches below normal. This moisture deficiency, coupled with hot winds in early summer, caused considerable burning in all of the grain plats, thereby producing uneven stands. Under such conditions, it is highly probable that yields computed by square yards more nearly represent the true yielding abilities of the varieties. The small difference in yields between plat and square yards on all classes of grain for the season of 1930 would lead one to conclude that for all practical purposes the square yard method may be substituted for plat yields.

Table 1 also shows a statistical analysis of the same grain data. All the constants, except the probable error of difference for oats in the season of 1929, strongly indicate that square yard yields can be satisfactorily substituted for plat yields. The high correlation between yields of plats and square yard yields indicate the relative value of the two methods for determining yields on plats. The difference between plat and square yard means and coefficients of variability is too small in all cases, except for barley and oats for 1929, to be considered significant.

Table 2 shows the difference between the average yield of 27 plats each of spring wheat, oats, and barley and the average yield of their respective square yards. The difference between the average yield of 27 plats of Jenkin and the average of their 162 square yards for the season of 1929 is 2.6 bushels, or 6%, in favor of square yard yields. This difference is not significant as indicated by the probable error of difference and coefficient of variation. The results from these statistical constants are supported by a high correlation coefficient. When Student's method is used on the same data the odds strongly indicate that square yard yields can not be safely substituted for plat yields. Jenkin for the season of 1930 shows a difference of 0.9 bushel between plat and square yard yields. This difference is so small that the odds strongly favor the substitution of the square yard yields for plat yields. A correlation of 0.940 ± 0.0745 supports the above conclusions as to the possibility of substitution of square yards for plat yields. However, the high odds obtained by Student's method are over four times its probable error.

Federation for the season of 1929 shows a difference of 5.4 bushels between the average yield of plat and square yard. This difference is significant and indicates that it would be unwise in this case to substitute square yard yields for plat yields. A correlation of 0.7444 ± 0.5789 indicates a possibility of substitution of square yard yields for plat yields. Student's method indicates the impracticability of the use of square yards for the determination of yields on plats. The data on Federation for the season of 1930 show a deviation 1.6 bushels between plat and square yard yields. This difference is not significant as indicated by probable errors of differences of mean and coefficient of variability. The high correlation of 0.9340 ± 0.2456 indicates that square yards may be safely substituted for plat yields. However, the odds obtained by Student's method are against such a substitution,

TABLE 2. *Comparing yearly plat yields per acre of Jenkin, Federation, and Red Bobs wheat, Victory oats, and Trebi barley with their respective square yard yields for the season of 1929 and 1930.*

Classification	Spring wheat, bu. per acre						Markton oats, 1929, bu. per acre	Trebi, barley, 1929, bu. per acre
	Jenkin, 1929	Jenkin, 1930	Federation, 1929	Federation, 1930	Red Bobs, 1929	Red Bobs, 1930		
Mean of 27 field plats	40.8 ±0.7174	14.1 ± 1.0972	31.5 ±0.2557	20.7 ± 1.0195	28.9 ±0.810	26.3 ±0.6332	70.7 ±1.3526	42.9 ±1.6673
Mean of 162 square yards	43.4 ±1.094	15.0 ± 1.449	36.9 ±0.3515	22.3 ± 1.2799	33.4 ±0.9364	26.5 ±0.6537	69.2 ±1.210	51.5 ±1.0522
Difference	2.6 ±1.306	.9 ± 1.100	5.4 ±0.434	1.6 ± 1.295	4.5 ±1.238	.2 ±0.904	1.5 ±1.810	8.6±2.093
Coefficient of variability of plats	13.557 ±1.267	56.418 ± 7.044	6.272 ±0.5757	37.624 ± 6.765	21.5504±2.0680	18.5464±1.760	8.9687±1.3527	15.073±2.4500
Coefficient of variability of square yards	19.408 ±1.850	70.161 ± 9.623	7.338 ±0.6735	44.216 ± 8.973	21.615 ±2.0746	19.002 ±1.806	8.1961±1.2362	9.087±1.4447
Difference	5.851 ±2.264	13.743 ±12.333	1.066 ±0.885	6.592 ±11.414	.65 ±2.930	.44 ±2.521	.77 ±2.312	5.99±2.844
Correlation coefficient	0.7828±0.0745	0.9408± 0.0745	0.7444±0.5789	0.9340± 0.2456	0.9515±0.1228	0.7268±0.0908	0.6727±0.1731	0.9318±0.0281
Student's method (odds)	181:1	286:1	9999:1	9999:1	9999:1	1:1	3.19:1	332:1

therefore, it would be unwise to use the square yard method for determining yields on plats.

The difference between plat and square yard yields for Red Bobs for the season of 1929 indicates that square yard yields cannot be substituted for those of plat yields, while the 1930 data indicate that the substitution of square yard yields may be satisfactorily made for plat yields. The high correlations for both years indicate the feasibility of substitution of square yard yields for those of plat yields. The odds obtained by Student's method on the 1929 data are strongly against such a substitution, while the odds on the 1930 data suggest that such a substitution can be made with a considerable degree of accuracy.

The oat data for the seasons of 1929 give a difference of 1.5 bushels between square yard and plat yields. This difference is not significant in that it is less than three times its probable error. The correlation is favorably high, indicating a safe substitution of square yard yields for plat yields. The odds by Student's method are not significant and indicate that square yard yields may be safely used in place of plat yields in computing yields on plats.

In the barley data for 1929 a difference of 8.6 bushels between plat and square yard yields is so great that it would be unwise to substitute square yard yields for plat yields. However, the high correlation indicates that square yard method for determining yields can be used in place of plat yields. The odds as determined by Student's method are strongly against such a substitution.

The data in Table 3 show the relative difference between yields computed on entire plats and yields computed from 3, 6, 9, 12, 15, and 18 square yards. In general, it is true that as the number of square yards taken within a plat increases the difference between plat yields and square yard yields decreases. The difference between 3, 6, and 9 square yards and their respective plat yields are significant. While on the other hand, the difference is so small between 12, 15, and 18 square yards and their respective plat yields that they can hardly be considered significant. It would appear, therefore, that for all practical purposes the yields computed from 12, 15, or 18 square yards may be safely substituted for plat yields.

SUMMARY AND CONCLUSIONS

The difference between plat and square yard yields range from 0.2 of a bushel to 3.1 bushels on all classes of grains for the seasons of 1929 and 1930, with the exception of the oat varieties for the seasons of 1929, which gave a discrepancy of 6.1 bushels. The difference of 3.1 bushels between plat and square yard yields is perhaps within the probable error. However, a difference of 6.1 bushels between plat and square yard yields is no doubt highly significant.

Fifty-four plats of Jenkin wheat show a difference of 2.6 bushels and 0.9 bushel, respectively, for the seasons of 1929 and 1930. These differences are not significant as indicated by probable errors of the difference. However, when Student's method is used on the same data the odds indicate that yields from square yards can not be substituted for plat yields. High positive correlations for both seasons indicate that such a substitution can be made satisfactorily.

TABLE 3.—*Determining the correct number of square yards that are necessary to take within a plat from data on winter and spring wheat varieties for the season of 1931.*

Classification	Winter wheat, bu. per acre			Spring wheat, bu. per acre					
	Mosida	Triplet	Ridit	Red Bobs	Red Bobs sel.	Red Bobs sel.	Federation	Baart sel.	Baart sel.
Average yield of 3 plats....	60.00	64.4	50.7	28.6	27.6	31.6	33.9	31.3	33.9
Average yield of 3 square yards.......	67.20	76.3	57.7	34.1	23.9	28.8	31.9	27.8	29.0
Difference....	7.20	11.9	7.0	5.5	3.7	2.8	2.0	3.5	4.9
Average yield of 3 plats....	60.00	64.6	50.7	28.6	27.6	31.6	33.9	31.3	33.9
Average yield of 6 square yards.......	68.60	71.3	54.4	31.5	29.3	29.6	30.0	25.0	25.7
Difference....	8.60	6.7	3.7	2.9	1.7	2.0	3.9	6.3	8.2
Average yield of 3 plats....	60.00	64.6	50.7	28.6	27.6	31.6	33.9	31.3	33.9
Average yield of 9 square yards.......	67.20	68.4	51.5	30.3	31.9	31.7	32.8	25.6	29.6
Difference.....	7.2	3.8	0.8	1.7	4.3	0.1	1.1	5.7	4.3
Average yield of 3 plats....	60.00	64.6	50.7	28.6	27.6	31.6	33.9	31.3	33.9
Average yield of 12 square yards.......	64.90	66.2	50.0	29.2	29.8	30.7	33.3	28.3	30.2
Difference....	4.90	1.6	0.7	0.6	2.2	0.9	0.6	3.0	3.7
Average yield of 3 plats....	60.00	64.6	50.7	28.6	27.6	31.6	33.9	31.3	33.9
Average yield of 15 square yards.......	63.70	63.4	50.2	30.5	32.2	32.9	34.3	31.4	32.1
Difference....	3.70	1.2	0.2	1.9	4.6	1.3	0.4	0.1	1.8
Average yield of 3 plats....	60.00	64.6	50.7	28.6	27.6	31.6	33.9	31.3	33.9
Average yield of 18 square yards.......	63.40	63.7	49.7	31.2	32.2	34.1	34.1	33.9	33.2
Difference....	3.4	0.9	1.0	2.6	4.6	2.5	0.2	2.6	0.7

A difference of 5.4 bushels between plat and square yard yields for Federation for 1929 is too great to permit the substitution of one method for the other. A difference of 1.6 bushels between plat and square yard yields for Federation for 1930 is so small that it is safe to assume that the square yard method for computing yields on cereals can be substituted for the plat method.

The biometrical findings on data for Red Bobs for the seasons of 1929 and 1930 parallel those for Federation for the same seasons, with the exception of the odds by Student's method, which indicates that square yard methods for the season 1930 can be substituted for the plat method.

All the results from the statistical constants used on Markton oats indicate that the square yard method can be substituted for the yield obtained on entire plat.

A difference of 8.6 bushels between square yard and plat yields for Trebi barley is too great to warrant a substitution. The odds for all the constants except correlation are against the substitution.

The data on the number of square yards to take within a plat indicate that for all practical purposes from 12 to 18 square yards should be taken in a plat before yields computed on square yards may be considered comparable to yields computed on an entire plat.

LITERATURE CITED

1. ARNY, A. C., and GARBER, R. J. Field technic in determining yield of plats on grain by rod-row methods. Jour. Amer. Soc. Agron., 11: 33–37. 1919.
2. ARNY, A. C., and STEINMETZ, F. H. Field technic in determining yields of experiment plats by square yard method. Jour. Amer. Soc. Agron., 11: 81–106. 1919.
3. KIESSELBACH, T. A. Studies concerning the elimination of experimental error in comparative crop tests. Nebr. Agr. Exp. Sta. Res. Bul. 13: 1–95. 1918.
4. HULBERT, H. W., MICHELS, C. A., and BURKART, F. L. Border effect in variety tests of small grains. Idaho Agr. Exp. Sta. Res. Bul. 9. 1931.

THE EFFECT OF DEPTH OF PLANTING ON THE GERMINATION OF SOYBEAN VARIETIES[1]

R. E. STITT[2]

Poor stands of soybeans have often been attributed to the formation of a crust on the surface of the soil. This hardening of the soil surface is usually more of a factor in heavy clay soils than in loam or sandy soils. In order to study the relation of soil type to germination a depth of planting experiment was made using a clay and a sandy loam with different varieties of soybeans.

Piper and Morse[3] studied depth of planting with Mammoth and

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[1] Contribution from the Department of Agronomy, Massachusetts State College, Amherst, Mass. Part of a thesis submitted to the faculty of the Massachusetts State College in partial fulfillment of the requirements for the degree of master of science, and prepared under the supervision of Prof. A. B. Beaumont. Received for publication October 12, 1934.

[2] Formerly Graduate Assistant in Agronomy, Massachusetts State College; Now Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3] PIPER, C. V., and MORSE, W. J. The Soybean. New York: McGraw Hill Book Co. 1923.

Peking varieties of soybeans and found that the stand was reduced slightly at a depth of 4 inches. In Tennessee, Mooers[4] found that the Ito San variety, under favorable conditions, failed to reach the surface when planted 6 inches deep and that the stand was very poor at 5 inches. The stand was apparently perfect between depths of 1 and 4 inches. At the Kentucky Experiment Station Kinney and Roberts[5] observed that small-seeded varieties germinated more satisfactorily than the large-seeded ones in hard crusted ground. They attributed this to the fact that the cotyledons were smaller and encountered less resistance in breaking through the surface.

Weighed samples of 100 seeds each of the Habaro, Ito San, and Illini varieties of soybeans were planted in 3-gallon glazed earthen pots at depths of 1, 2, 3, 4, and 5 inches. Agawam very fine sandy loam which contained 80% sand, 12% silt, and 8% clay and Suffield clay which contained 8% sand, 18% silt, and 74% clay were used as the media of growth. Duplicate sets of pots were kept under two different temperature conditions; one set in a heated greenhouse and the other in an unheated glasshouse. Soil temperatures recorded at 8:00 a. m. and 5:00 p. m. averaged 68.1° F in the greenhouse and 59° F in the glasshouse. The soil moisture was regulated by pouring water through a glass tube 1 inch in diameter which extended into a shallow layer of gravel at the bottom of the pot. A small quantity of water was maintained in the gravel layer so that capillarity was constant.

To obtain a germination standard for comparison, duplicate samples (100 seeds each) of each variety were placed in a seed germinator for 7 days at alternating temperatures of 68° F at night and 86° F during the day. The results of the test in the seed germinator for the different varieties were Habaro and Ito San 93% and Illini 94%, which compared with percentages of 93, 91, and 95, respectively, when covered with 1 inch of soil.

EXPERIMENTAL RESULTS

The maximum percentage of emergence and the number of days between planting and first and last emergence are given in Table 1. Considering the sandy loam at an average temperature of 68.1° F a satisfactory medium for the germination of soybeans, the data show a slight decrease in the number of plants emerging with the increase in depth up to 4 inches. Only a few plants were able to push through the 5-inch layer of soil. The number of emerged plants was satisfactory from depths of 1 to 4 inches with some exceptions. The lower percentages of emergence of the 3-inch planting of Habaro and Illini and the 3- and 4-inch plantings of Ito San may have been due to the fact that the seed in these samples were larger than those in the other samples. The effect of size of seed on emergence is best brought out by considering the data of all of the 5-inch plantings. The Habaro variety, weighing 20.45 grams per 100 seed, germinated 9%; Ito San, weighing 17.05 grams, 17%; and Illini, weighing 12.08 grams, 40%.

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[4] Mooers, C. A. The soybean. A comparison with the cowpea. Tenn. Agr. Exp. Sta. Bul. 82. 1908.

[5] Kinney, E. J., and Roberts, George. Soybeans. Ky. Agr. Exp. Sta. Bul. 232. 1921.

TABLE 1.—*Maximum emergence and number of days to first and last emergence of Habaro, Ito San, and Illini soybeans under different soil and temperature conditions.*

Depth of seeding, inches	Habaro emergence			Ito San emergence			Illini emergence		
	%	No. of days to		%	No. of days to		%	No. of days to	
		First	Last		First	Last		First	Last
Sandy Loam Soil at 68.1° F									
1	92	5	8	95	6	12	94	5	10
2	90	7	15	91	7	15	89	6	13
3	85	10	21	67	10	24	84	8	14
4	93	9	20	77	10	20	89	9	20
5	5	24	26	11	21	26	61	12	24
Clay Soil at 68.1° F									
1	94	6	11	86	6	14	96	6	10
2	82	8	20	81	6	15	85	6	13
3	67	8	20	82	7	15	86	7	16
4	50	9	26	49	8	27	53	7	26
5	21	10	26	34	13	26	56	11	26
Sandy Loam Soil at 59° F									
1	95	19	28	79	19	29	86	19	28
2	92	23	31	80	24	28	86	25	33
3	81	26	31	82	27	30	80	25	33
4	82	29	34	70	28	35	45	26	35
5	4	35	35	4	34	35	26	30	36
Clay Soil at 59° F									
1	72	26	34	85	27	31	93	20	28
2	64	27	34	35	27	35	87	26	31
3	20	29	35	42	28	34	25	28	36
4	11	31	35	19	33	35	19	31	34
5	7	33	36	17	33	36	18	28	35

Plantings at depths of 2, 3, and 4 inches required from 3 to 12 days longer for total emergence than those of 1 inch, which would give considerable advantage in early growth to shallow seedings. The time required for emergence lengthened as the depth of planting increased, becoming very marked at 5 inches.

EFFECT OF SOIL TYPE

At the 1-inch depth soil type was not a factor in influencing emergence as the number of seedlings and the time required for emergence were similar in the sandy loam and clay. At the greater depths the plants were not able to push their way readily through the clay which formed a hard crust. The seedlings which reached the surface from a depth of 3 inches or more in the clay took advantage of the cracks which appeared as the plants lifted the hard crust of the soil. Growth differences associated with soil type appeared in the form of heavier leaf growth with shorter first internodes of the plants on the sandy soil compared with those on the clay soil, although these differences were not pronounced in the Illini variety.

EFFECT OF TEMPERATURE

With an average soil temperature of 59° F as compared with 68.1° F, germination proceeded at a much slower rate. In the warmer soil the first plants emerged in 5 days, while in the cooler soil 19 days were required. The cooler temperature reduced germination slightly at all depths in the sandy loam, while the number of seedlings which emerged from depths greater than 1 inch in the clay soil at 59° F was not satisfactory with the exception of those of the Illini variety planted 2 inches deep.

SUMMARY

Studies were made of the relationship between depth of seeding, soil type, soil temperature, and the size of seed and their effects on the germination of the Habaro, Ito San, and Illini varieties of soybeans.

There was a reduction in stand from seeding deeper than 2 inches in a fine sandy loam and 1 inch in a clay soil. Satisfactory stands were secured to depths of 4 inches in the loam and 2 inches in the clay.

Increasing the depth of planting caused a progressive lengthening of the germination period.

Germination at cool temperatures was slow and resulted in a reduction of the number of emerged seedlings.

Smaller seeded varieties germinated in less time and better at greater depths of seeding than the larger seeded varieties.

BREEDING FOR FIBER LENGTH REGULARITY IN COTTON[1]

G. N. Stroman[2]

Quality of cotton is receiving the attention of all who are closely associated with the cotton industry. From the viewpoint of the breeder, however, quality has in the past had a very vague meaning. In the cotton market it has meant only grade and staple, or length. Grade, is dependent upon care in harvesting and ginning of the crop and upon weather conditions. Staple depends somewhat upon environmental conditions (4)[3] during the growth of the crop, but it depends mostly upon the inherent length of the variety being grown. It is only very recently (1) that length of lint has been recognized as definitely related to spinning value.

COTTON BREEDERS AND QUALITY

The relation of length to spinning value leads to a definite meaning of quality from the breeder's viewpoint. Turner and Uenkataraman (5) have shown that characters such as ribbon-width, strength, convolutions, or rigidity are not of value in predicting the spinning value of a cotton. They found that fiber length and fiber weight per inch are related to spinning value. The long fibers have been recognized

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[1] Contribution from the Department of Agronomy, New Mexico Agricultural Experiment Station, State College, N. M. Scientific Paper No. 14. Published with the approval of the Director. Received for publication October 13, 1934.

[2] Associate Agronomist.

[3] Figures in parenthesis refer to "Literature Cited," p. 1011.

(6) as being the fine fibers, which for practical purposes leaves length of fiber as of greatest importance for the use of the cotton breeder.

Length of lint has long been recognized by cotton breeders as an important character of quality, but uniformity of length was important only as regards even running plants of the strain or variety. With the advent of a fiber sorting machine adapted to the breeder (7) and with the advance in cytological and morphological analysis of the fibers in their early growth, (8, 9, 10), more emphasis should be placed on the uniformity of the fiber as to its length. Furthermore, as the breeder works with individual plants as the breeding units, he should be concerned with the uniformity of the fiber of these individuals. It seems logical that with all the advance made in genetics in the past few years, it might be possible to produce by analysis of progenies or by hybridization of species or strains a variety that would closely approach the ideal of having a definite narrow range of regularity of fiber.

It seems that cotton breeders should concern themselves about fiber regularity rather than irregularity. However, if there is more of one, there is less of the other. Clegg (11) gives a method of obtaining an effective spinning length of lint by use of a fiber sorter. Ahmad and Navkal (1) discussed fiber irregularity and expressed it as the percentage ratio by weight of all fibers in a representative sample which measured less than three-fourths of the modal length. This gives a measure of the undesirable fibers in a sample of cotton but does not show the relative length of the desirable fibers of a sample. Also, they show that the correlation coefficient between fiber irregularity, which they called *K*, and the highest warp count[4] was smaller than was the mean fiber length and the highest warp count. Furthermore, they found that the multiple correlation coefficient, using the characters highest warp count, mean fiber length, fiber weight per inch, and fiber length irregularity, with the first named as the primary, was no higher than the multiple coefficient using only the first three mentioned. It seems as if they show, then, that the measure of fiber irregularity as they define it would add nothing, owing to the fact that the ratio of three-fourths of the modal length does not indicate anything of the length of the fibers. A long cotton might have more fiber irregularity than a short cotton and to use this measure effectively the mean length would also have to be given.

The writer in a previous publication (2) used the character of percentage 1⅛-plus fibers. There seemed to be a need of such a term to show regularity of the desirable lengths of cotton for New Mexico. The complement of this figure for this character would be the irregularity of the fiber or the percentage of the undesirable lengths. Also, for New Mexico, in order to build up a favorable reputation with the spinners, it is necessary that the cotton be uniform as to the desirable lengths. The 1⅛-plus fibers include only three lengths, namely, 1⅛, 1¼, and 1⅜ inches, respectively. Certain individuals of the 1933 progeny test ran as high as 69% of 1⅛-plus fibers.

[4] Highest warp count is the term used in India to denote a single index of spinning value of a cotton. "And is, briefly, the finest count of warp yarn that can be spun economically with a standard medium twist and with only a few breakages in spinning, and have a certain standard strength..."

This report is prepared to show some of the progress made in 2 years' work at the New Mexico Experiment Station in breeding for fiber regularity by selecting for high percentage of 1⅛-plus fibers. In this report there has been no attempt to make a factorial genetic analysis, but the data will show that the character percentage of 1⅛-plus fibers does run in certain families; also that in selecting high percentage 1⅛-plus fibers some of the progeny of most families will be found to have the same degree of fiber regularity as did its parent.

MATERIAL AND METHODS

The material used is that of the data from the regular progenies in the cotton breeding work at this Station. The following strains and some of their progeny will be used: 504, 707, 550, 593, and 682. All of these were 1931 families except 707 and 682 which were of the season of 1932. However, all data that are reported came from 1932 and 1933 records.

Family 504 was the outstanding family of 1931 as to length and uniformity of length. The uniformity of length in that year was measured by the narrow range in length of the progeny of that year. This family was also desirable as to the other characters that were noted.

The methods used have been described in a previous publication (2). The Pressley (7) sorter was used in making these studies. Ten seeds were taken from each individual plant sample. Each of these came from the middle of a lock and each from a different boll. These were prepared for the sorter by being carefully combed, first parting the lint right and left from the middle of the seed. One side only was carefully combed. The 10 seeds were then placed in the sorter and the different lengths drawn from the sorter. The lint of each length was weighed to the nearest half milligram on a balance capable of measuring to the tenth milligram. However, the weightof each was recorded only to the nearest milligram. The lengths drawn, in inches, were 1⅜, 1¼, 1⅛, 1, ⅞, and ¾ and less. The latter length was obtained by dropping all combs after the ⅞-inch drawing and pulling all the remaining fibers. The weights of the lengths 1⅛, 1¼, and 1⅜ inches were added and divided by the total amount by weight to arrive at the percentage of 1⅛-plus fibers. Expressed in a formula it is:

$$\frac{\text{Weight of } 1\tfrac{1}{8},\ 1\tfrac{1}{4}, \text{ and } 1\tfrac{3}{8} \text{ fibers} \times 100}{\text{Weight of all lengths of the sample}} = \text{Percentage } 1\tfrac{1}{8} \text{ inch-plus fibers.}$$

Some samples will comb out more waste lint than others. This may be attributable to breakage of fibers and indicates a weakness of fiber which helps in the elimination of weak-fibered strains because the total amount of combed fibers is taken into consideration when selecting the individuals to plant. Also, the cotton on certain individual plants will comb out more than that on others, owing to the fibers being held weakly on the seed, a condition which probably has no relation to strength of the fiber. In addition to percentage of 1⅛ inch-plus fibers, the length of lint and total fibers of the sample are given in certain parts of the data. The length of lint is measured in thirty-seconds of an inch and was stapled by the El Paso office of the Division of Cotton Marketing of the Bureau of Agricultural Economics.

The total fibers of the sample are the total in milligrams of the pulled sample. It is the sum of all the lengths of the sample.

In 1932, the year the parents of the progenies were tested, the humidity of the laboratory was not controlled. In 1933, the year of the progeny as given here, the humidity of the laboratory was controlled by means of a humidifier which was made at this Station. It controlled the relative humidity between 55° and 65°. Records of total sorted fibers show that higher humidity is conducive to better combing.

The combing was done by several different trained workers. It would have been more desirable to have such work done by one man. However, these men were very carefully trained to comb in practically the same mechanical way. Each man completed his own sample, but when more than 1,200 samples are to be run, as during the past season, at least three combers are required.

THE DATA

The data are presented in the form of summaries, except in Table 4, where they might be called representative data. However, the summary data are representative in the way that there are many more progenies of other families that could have been included; for they bear out the results obtained by the ones that are given. In Table 1 is given the summary of the data on the 1933 progenies of the 504 strain. In Table 2, the summary data on the 1933 progenies of strains 707, 550, and 682 are given, and in Table 3 will be found those of the 593 strain as well as nine check rows. The number of individuals in each progeny is not sufficient to make any kind of genetic

TABLE 1.—*Strain 504 as regards parental percentage $1\frac{1}{8}$-plus fibers and length of lint and the mean and range of the progeny with respect to the same characters.*

Family No.	Percentage $1\frac{1}{8}$-plus fibers				Length of fiber in 32d inch		
	Parent	Progeny			Parent	Progeny	
		Mean	No. of plants	Range		Mean	Range
798	35.7	26.4	10	6-39	36	33.9	33-34
819	42.8	45.7	7	27-56	37	36.3	36-37
826	26.0	21.9	9	10-38	38	35.1	35-36
844	42.0	22.8	5	12-31	37	34.6	34-35
910	26.0	14.1	5	10-23	38	34.8	34-35
929	3.7	6.0	5	3-8	35	—	—
930	20.9	23.9	6	13-40	36	—	—
938	10.0	11.3	5	9-14	36	35.6	35-36
956	26.7	15.5	10	6-27	38	35.4	34-36
1003	33.7	25.1	5	18-40	38	37.0	36-38
1009	26.9	21.9	4	19-29	38	36.0	36-36
1051	40.0	21.4	9	10-38	37	35.0	34-36
1053	17.8	13.2	12	7-22	35	35.9	35-36
1056	33.5	19.5	5	11-33	37	36.8	36-37
1057	34.3	23.9	4	21-27	38	37.0	37-37
1061	40.3	27.3	10	13-44	37	37.0	36-38
1064	47.2	25.7	10	10-37	38	36.4	36-37
1065	40.1	20.2	18	8-47	37	34.4	33-35

analysis of the characters shown. They seem sufficient, however, to show that the percentage 1⅛-plus does behave as a character that can be used with confidence in breeding strains of cotton.

TABLE 2.—*Strains 707, 550, and 682 as regards parental percentage 1⅛-plus fibers and length of lint and the mean and range of the progeny with respect to the same characters.*

Family No.	Percentage 1⅛-plus fibers				Length of fiber in 32d inch		
	Parent	Progeny			Parent	Progeny	
		Mean	No. of plants	Range		Mean	Range
				707 Strain			
808	35.3	17.6	11	13–23	37	34.5	34–35
821	30.8	26.5	13	13–40	36	35.5	34–36
827	18.9	30.7	12	12–54	37	35.8	35–36
845	37.6	12.7	15	2–31	36	34.2	33–35
852	40.8	12.6	14	3–27	37	35.1	34–36
877	28.7	19.8	10	8–34	36	34.0	34–34
887	30.2	25.1	14	13–38	36	35.5	35–36
931	33.6	18.8	13	9–31	37	—	—
954	44.9	22.1	10	6–53	37	35.9	36–36
961	32.6	9.9	10	3–17	37	34.3	34–35
				550 Strain			
824	10.1	21.3	8	8–45	36	34.9	34–35
1032	19.0	11.7	26	1–35	36	34.0	33–35
823	15.0	45.6	8	29–60	36	35.7	35–36
906	31.1	31.9	28	14–51	36	35.2	35–36
1033	35.3	22.0	7	14–27	—	34.5	34–35
1034	8.7	6.7	5	1–13	34	34.6	34–35
800	29.5	18.4	13	8–38	36	35.8	35–36
865	35.4	22.5	9	5–41	36	35.3	35–36
848	36.8	25.6	7	7–35	35	34.2	34–34
905	31.5	14.4	10	9–29	36	35.5	34–36
1004	14.5	10.0	8	3–17	36	35.0	34–36
				682 Strain			
801	12.8	7.8	11	2–12	37	35.4	34–36
829	35.2	38.4	16	12–69	37	36.4	35–37
859	46.6	27.1	11	15–40	37	36.1	36–37
912	32.9	30.8	10	12–56	38	36.6	36–37
968	32.3	17.8	2	14–22	37	34.5	34–35
1023	41.4	34.9	8	11–51	38	34.6	34–35

In Tables 1, 2, and 3 the parent individual plant character of percentage 1⅛-plus and length of lint are given. The progeny type is shown by the mean and the variability by the range. The number of individuals averaged from each progeny is also given.

The mean percentage 1⅛-plus fibers of the progeny seldom exceeds the parental characteristic and in the majority of cases the same percentage of 1⅛-plus as in the parent is found among some of the progeny. Where this is not the case the progeny falls short of the parental character. There is only one exception to this which occurs with the 823 family of the 550 strain (Table 2). In this case the parent had

15% of 1⅛-plus fibers, but the progeny had a mean of 45.6% and a range of 29 to 60%. This is not surprising, owing to the small number of individuals which were used in making the sorter tests.

The strains 504, 707, 550, and 682 are the principal ones being used in breeding for fiber regularity. In the 1934 plantings 70% of all progenies come from these four strains. The 682 strain gave, in 1933, the highest individuals with respect to percentage of 1⅛-plus fiber. Table 3 gives the summary of the data on the 593 family which is exceedingly low for percentage of ⅛-plus fibers. Summary data on the check rows are also included in Table 3. These checks came from the seed of the variety commonly grown in New Mexico and represent a highly bred strain of cotton. The seed of these 1933 checks was from seed that was grown in 1934 by growers of the New Mexico Crop Improvement Association. In comparing these checks with strains 504, 707, 550, and 682 with respect to percentage 1⅛-plus fibers, the checks are very much lower in regularity of the desired fibers and also in length of lint than the best of the strains reported on in this article.

TABLE 3.—*Strain 593 and the check rows as regards percentage 1⅛-plus fibers and length of lint.**

Family No.	Percentage 1⅛-plus fibers				Length of lint in 32d inch		
	Parent	Mean	No. of plants	Range	Parent	Mean	Range
				593 Strain			
838.......	3.0	2.9	2	2–3	33	33.0	32–34
940.......	1.2	6.6	39	1–13	32	33.3	33–34
962.......	2.3	2.7	32	0–17	32	33.7	32–35
979.......	5.7	10.1	3	2–25	33	34.7	34–35
			Checks				
846.......		9.4	10	5–14		35.0	34–36
863.......		10.9	10	2–23		33.0	33–33
874.......		15.4	10	6–31		35.6	35–36
883.......		8.3	10	3–21		33.9	33–34
947.......		10.7	10	3–17		34.3	34–35
955.......		15.1	10	5–26		34.0	34–34
984.......		14.2	10	9–29		35.6	35–36
994.......		6.4	10	1–14		33.8	33–34
1015.......		4.1	10	1–7		33.4	33–34

*Parental characters and progeny type and variability are shown of 593. Check rows planted to College Acala, the standard variety of New Mexico, give the type and variability of consecutive plants.

Usually, it has been the writer's observation that in the majority of cases lower length of fibers as reported by the classer will be directly reflected in the percentage of 1⅛-plus fibers, however this is not always the case. Biometrical relationships of the different characters, which include both percentage 1⅛-plus and length of lint, have been calculated and will be published at a later date.

SORTER DATA

In Table 4 are given the sorter data on family 829 and its nearest check. It so happened that in this check, row 825, there were only four individuals tested on the sorter; however, it compares favorably with the other checks that were sorted. Table 4 is given as representative of all the data. In it can be seen amounts by weight of different lengths in which the percentage of 1⅛-plus fiber is high in some individuals and low in others. Upon looking over Table 4, it is apparent that there is a great amount of irregularity of the fiber and that in those individuals having a high percentage of 1⅛-plus fibers there is a correspondingly lower amount of the short fibers. This, however, is to be expected.

TABLE 4.—*The sorter distributions by weight, total amount of the pulled sample, and percentage 1⅛-plus fibers of family 829 and from random plants of its nearest check.*

Plant No.	Milligrams for							1⅛-plus %
	1⅜ in.	1¼ in.	1⅛ in.	1 in.	⅞ in.	¾ in. and less	Total	
				Family 829				
1......	10	52	99	87	38	51	337	47.8
2......	29	65	86	43	22	55	300	60.0
3......	44	86	100	32	17	55	334	68.9
4......	64	76	107	50	25	59	381	64.8
5......	22	72	113	59	31	47	344	60.2
6......	3	11	71	112	68	76	341	24.9
7......	0	3	29	76	74	73	255	12.5
8......	9	37	93	90	47	67	343	40.5
9......	15	46	90	71	31	44	297	50.8
10......	1	6	31	57	51	50	196	19.4
19......	5	33	77	65	30	46	256	44.9
21......	1	6	56	97	66	82	308	20.5
26......	11	32	69	45	21	46	224	50.0
29......	1	7	38	62	46	69	223	20.6
40......	0	1	40	78	70	66	255	16.1
A......	0	5	25	66	45	86	227	13.2
				Checks				
825–8....	0	3	20	66	72	107	268	8.6
825–12...	0	2	18	58	71	111	260	7.7
825–13...	1	5	43	72	59	66	246	19.9
825–21...	1	7	62	85	100	113	368	19.0

DISCUSSION

Biologically, the goal of obtaining a strain of cotton with a spread of only ⅛ or ¼ in the length of its fibers probably can never be attained. However, in 2 years' work with the sorter test, the percentage of the fibers of 1⅛ to 1⅜, as shown by the comparison of the progenies of the high strains with those of the checks, has been doubled. Also, in family 829 of strain 682 (Table 2) there is the possibility of producing a strain that will average more than four times the mean of the checks, but anything further than this cannot be predicted.

When a uniformly high percentage of 1⅛-plus fibers in a strain of cotton as measured by the variation from plant to plant has been developed, the question may arise as to just what effect it will have on the value of the cotton for the farmers of New Mexico or the surrounding territory who might grow this cotton.

It seems that there might be two very important reasons for higher values for this cotton. One of these is an immediate return to the farmers who grow it. This would be due to the cotton having a greater percentage of the longer fibers, which in turn would cause it to be classed as being of the greater lengths. However, the classers that stapled the individual samples as reported here have not always recognized the higher percentage of 1⅛-plus cotton. This may be attributable to the fact that the classing of this cotton was done after the cotton had been ginned on a small high-speed sample gin which is very drastic in its effect on the lint. A glance at the 682 progenies in Table 2 will show that a high percentage of 1⅛-plus cotton was recognized to some extent by the classers.

The other effect that high percentage of 1⅛-plus cotton would have on the price of the cotton paid to the farmer is that spinners would eventually recognize cotton of the more uniform lengths. In India, where many spinning data in relationship to the characters of cotton fiber have been studied (1, 3, 5), it is recognized that uniformity of length is the greatest factor in high spinning quality.

When the manufacturer appreciates this superior trait of quality, strains of cotton with uniformity of desired length of lint should bring extra premiums to the farmers in areas where it can be grown successfully.

SUMMARY

Work at the New Mexico Agricultural Experiment Station on fiber regularity is reported. Summary data on four principal strains that are high as regards percentage of 1⅛-plus fibers are given.

Percentage of 1⅛-plus fibers is the percentage of cotton of 1⅜, 1¼, and 1⅛ inches in a sample that has been pulled from a cotton fiber sorter. In preparation for the sorter, 10 seeds are taken, each from different bolls, and carefully combed. They are then placed in the sorter and the different lengths separated and each length weighed on a milligram balance.

The four principal families as reported show that some progress has been made in the matter of breeding for high percentage of 1⅛-plus fibers. This is evident when they are compared with a strain with a low percentage of 1⅛-plus fiber and when compared with the check rows planted to a highly bred strain of cotton.

Strains having a high percentage of 1⅛-plus fibers should bring premium prices to the producer, due to such cotton being classed as of high length. Ultimately, certain spinners would probably pay a premium for such uniform cotton.

LITERATURE CITED

1. AHMAD, NAZIR, and NAVKAL, HARIRAO. Fibre-length irregularity in cotton. Ind. Cen. Cot. Com., Tech. Lab. Tech. Bul., Ser. B, 16. 1933.
2. STROMAN, G. N. Cotton breeding investigations, 1928 to 1932. N. M. Agr. Exp. Sta. Bul. 217. 1934.
3. KOSHAL, RAM SAREM, and AHMAD, NAZIR. Variations in the properties of the cotton fibre in relation to its position on the surface of the seed. Pt. 1 (1) Fiber-length, (2) Fiber weight, (3) Fiber strength. Ind. Cen. Cot. Com. Tech. Lab. Tech. Bul., Ser. B, 14. 1932.
4. REYNOLDS, E. B., and KILLOUGH, D. T. The effect of fertilizers and rainfall on the length of cotton fiber. Jour. Amer. Soc. Agron., 25: 756–764. 1933.

5. TURNER, A. J., and UENKATARAMAN, V. The foundations of yarn-strength and yarn extension. Pt. 1. The prediction of the spinning value of a cotton from its fiber-properties. Ind. Cen. Cot. Com. Tech. Lab. Tech. Bul., Ser. B, 17. 1933.
6. BALLS, W. LAWRENCE. Studies of Quality in Cotton. London: Macmillan & Company. 1928.
7. PRESSLEY, E. H. A new type of cotton sorter. Jour. Amer. Soc. Agron., 25: 88–98. 1933.
8. FARR, WANDA K. Cotton fibers, I. Origin and early stages of elongation. Contr. Boyce Thompson Inst., 3: 441–458. 1931.
9. ———, and CLARK, GEORGE L. Cotton fibers II. Structural features of the wall suggested by X-ray diffraction analyses and observations in ordinary and plane polarized light. Contr. Boyce Thompson Inst., 4: 273–295. 1932.
10. HAWKINS, R. S., and SERVISS, G. H. Development of cotton fibers in the Pima and Acala varieties. Jour. Agr. Res., 40: 1017–1029. 1930.
11. CLEGG, GLADYS G. The stapling of cottons: Laboratory methods in use at the Shirley Institute. Shirley Inst. Mem. 11. 1932.

THE EFFECT OF SOME FORMS OF NITROGEN ON THE GROWTH AND NITROGEN CONTENT OF WHEAT AND RICE PLANTS[1]

GUY THELIN AND A. B. BEAUMONT[2]

Rice and wheat have been used in many experiments on the absorption of different forms of nitrogen, but rarely have these two species been used in the same experiment. Owing to the close botanical resemblance between these cereals, it was thought desirable to determine their response to different chemical forms of nitrogen under identical cultural conditions. Vintula, an early maturing lowland rice, and Marquis wheat were the varieties grown.

METHODS USED

The plants were grown in a nutrient solution having the same mineral composition as that used in this laboratory for other studies[3] in absorption of nitrogen, except that 1 p. p. m. of manganese as the sulfate was added and ferric potassium tartrate was used at the rate of 5 p. p. m. This concentration of iron proved insufficient for rice and it was later increased. The equipment and technic employed were the same as have been previously described.[4] Six plants were replicated five times for each treatment. The plants were harvested in three stages of development, corresponding approximately to periods of 1, 2, and 3 months after transplanting.

Chemically pure sodium nitrate, ammonium sulfate, and urea supplied the nitrogen. Nitrate of soda was used in a concentration of

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[1] Contribution from the Department of Agronomy, Massachusetts State College, Amherst, Mass. Abstract of thesis submitted in 1931 by the senior author to the faculty of the Graduate School of the Massachusetts State College for the M. S. degree. Contribution No. 207 of the Mass. Agr. Exp. Station. Received for publication October 16, 1934.

[2] Graduate Student and Professor of Agronomy, respectively.

[3] BEAUMONT, A. B., EISENMENGER, W. S., and MOORE, W. J., JR. Assimilation of fixed nitrogen by grasses and clovers. Jour. Agr. Res., 47: 495–503. 1933.

[4] BEAUMONT, A. B., and LARSINOS, G. J. A water culture technic for studies in tobacco nutrition. Jour. Amer. Soc. Agron., 21: 150–155. 1929.

0.0278 mol., and the other nitrogen carriers in chemically equivalent concentration during the first and second stages of growth. During the third stage, the concentration of both minerals and nitrogen carriers was doubled. In addition to the single sources of nitrogen enumerated, solutions of different proportions of sodium nitrate and ammonium sulfate were used, as will be shown in the tables.

The culture solutions were changed twice weekly, which was frequent enough to prevent detectable changes in the form of nitrogen, except in later stages difficulty was experienced with the urea solution. Finally, the practice was adopted of placing the plants in fresh urea and mineral solutions on alternate days. This reduced hydrolysis of the urea to a minimum. The reaction of fresh solutions were pH 6.4 to 6.6, and the course of the reaction changes in the solutions was followed throughout the experiment.

After harvesting, the plants were dried at a temperature of 60° to 65°C, weighed, and ground for chemical analysis. Inorganic nitrogen was determined by a method used by Sessions,[5] and total nitrogen[6] by the Keldjahl method. Weights of the dried plants and nitrogen analyses are given in Tables 1 to 4.

DISCUSSION OF RESULTS

Both wheat and rice assimilated all forms of nitrogen to a certain extent. Both kinds of plants assimilated nitrogen in ammonium sulfate better in the early stage of growth than in the later stages. On the whole, rice was more at home with ammonium sulfate than wheat.

First stage.—During this stage wheat grew more vigorously, produced more dry matter per culture, and absorbed and assimilated more milligrams of nitrogen per gram of dry matter than did rice. Of the single sources of nitrogen, urea produced the most weight of wheat and ammonium sulfate the most of rice. The combination of 3 parts of nitrogen from sodium nitrate with 1 part from ammonium sulfate produced the most dry weight of each kind of plant. Sodium nitrate was superior to ammonium sulfate in the production of dry matter in wheat, while the reverse was true for rice. The presence of much more nitric than ammoniacal nitrogen in the wheat plants than in the rice plants at the end of the first stage suggests a preferential absorption of nitric nitrogen by wheat. The small amount of ammoniacal nitrogen in both species indicates that this form was rather well assimilated in the first stage of growth. Symptoms of the toxic action of ammonium sulfate previously described[7] began to be manifest on wheat but not on rice during this period.

Second stage.—At the end of the second stage of growth wheat was still ahead of rice in the production of dry matter in cultures supplied with urea and sodium nitrate, but rice had made better growth in cultures supplied with ammonium sulfate or combinations of ammonium sulfate and sodium nitrate. The best growth of wheat was

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[5] SESSIONS, A. C. A method for the determination of inorganic nitrogen in dried plant tissue. Soil Science, 29: 285–289. 1930.

[6] Total nitrogen was determined in the Feed Control Laboratory under supervision of P. H. Smith.

[7] See footnote 3.

TABLE 1.—*Mean dry weight in grams of wheat harvested at different stages in growth when supplied with different forms of nitrogen.*

Nitrogen carrier	End of first stage			End of second stage			End of third stage		
	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total
Check, no nitrogen	0.43	0.79	1.22 ± .02	0.93	0.71	1.64 ± .02	2.04	0.83	2.87 ± .04
Sodium nitrate	1.39	0.47	1.86 ± .05	4.68	1.31	5.00 ± .03	6.55	1.10	7.65 ± 1.26
Ammonium Sulfate	0.93	0.25	1.18 ± .03	1.39	0.33	1.72 ± .07	1.74	0.33	2.07 ± .10
Sodium nitrate, 1 part; ammonium sulfate, 3 parts	1.43	0.40	1.83 ± .04	2.24	0.55	2.79 ± .10	3.83	0.56	4.39 ± .34
Sodium nitrate, 2 parts; ammonium sulfate, 2 parts	1.59	0.43	2.02 ± .04	3.24	0.81	4.05 ± .29	5.68	0.98	6.66 ± .41
Sodium nitrate, 3 parts; ammonium sulfate, 1 part	1.84	0.48	2.32 ± .05	3.43	0.80	4.23 ± .20	11.28	1.36	12.64 ± .70
Urea	1.63	0.42	2.05 ± .07	6.51	1.18	7.69 ± .03	5.08	0.73	5.81 ± .53

TABLE 2.—*Mean dry weight in grams of rice harvested at different stages of growth when supplied with different forms of nitrogen.*

Nitrogen carrier	End of first stage			End of second stage			End of third stage		
	Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total
Check, no nitrogen	0.29	0.18	0.47 ± .02	1.09	0.74	1.83 ± .04	1.30	0.66	1.96 ± .10
Sodium nitrate	0.36	0.19	0.55 ± .04	2.31	0.70	3.01 ± .25	5.04	1.40	6.44 ± .50
Ammonium sulfate	0.63	0.17	0.80 ± .02	3.02	0.65	3.67 ± .09	3.42	0.75	4.17 ± .71
Sodium nitrate, 1 part; ammonium sulfate, 2 parts	0.59	0.18	0.77 ± .04	3.05	0.59	3.64 ± .20	3.39	0.57	3.96 ± .58
Sodium nitrate, 2 parts; ammonium sulfate, 2 parts	0.62	0.20	0.82 ± .04	3.42	0.65	4.07 ± .14	6.08	0.85	6.93 ± .74
Sodium nitrate, 3 parts; ammonium sulfate, 1 part	0.64	0.21	0.85 ± .05	4.09	0.85	4.94 ± .29	8.51	1.14	9.65 ± .58
Urea	0.58	0.23	0.23 ± .02	2.13	0.58	2.71 ± .25	—	—	— —

TABLE 3.—*Nitrogen fractions in wheat plants* as milligrams of nitrogen per gram of material air-dried at 60°–65° C.*

Nitrogen carrier	End of first stage				End of second stage				End of third stage			
	Ammonia N	Nitric N	Total in-organic N	Total N	Ammonia N	Nitric N	Total in-organic N	Total N	Ammonia N	Nitric N	Total in-organic N	Total N
Check, no nitrogen	0.29	0.21	0.50	18.63	0.27	2.86	3.13	23.68	0.73	1.81	2.54	19.12
Sodium nitrate....	0.23	5.90	6.13	43.01	0.45	11.11	11.56	39.86	0.50	14.02	14.52	36.58
Ammonium sulfate	1.45	0.81	2.26	42.73	11.39	2.36	13.75	43.83	13.57	5.00	18.57	45.25
Sodium nitrate, 1 part; ammonium sulfate, 3 parts...	0.61	3.46	4.07	49.60	9.04	3.78	12.82	47.86	15.07	6.19	21.26	56.46
Sodium nitrate, 2 parts; ammonium sulfate, 2 parts...	0.59	4.64	5.23	49.46	3.26	6.78	10.04	47.91	11.50	12.46	23.96	55.06
Sodium nitrate, 3 parts; ammonium sulfate, 1 part....	0.49	6.17	6.66	48.33	1.36	8.95	10.31	45.25	4.62	20.09	24.71	53.52
Urea...........	0.56	0.55	1.11	42.59	0.74	0.88	1.62	35.24	0.31	2.46	2.77	33.17

*Top and roots combined.

TABLE 4.—*Nitrogen fractions in rice plants* as milligrams of nitrogen per gram of material air-dried at 60°–65° C.*

Nitrogen carrier	End of first stage				End of second stage				End of third stage			
	Ammonia N	Nitric N	Total in-organic N	Total N	Ammonia N	Nitric N	Total in-organic N	Total N	Ammonia N	Nitric N	Total in-organic N	Total N
Check, no nitrogen	0.56	0.46	1.02	18.98	0.37	0.58	0.95	21.02	0.38	0.91	1.29	22.21
Sodium nitrate....	0.46	2.52	2.98	29.00	0.30	3.17	3.47	33.62	0.31	7.73	8.04	34.25
Ammonium sulfate	1.69	0.45	2.14	38.81	2.11	0.99	3.10	39.93	7.60	2.54	10.14	47.00
Sodium nitrate, 1 part; ammonium sulfate, 3 parts...	1.22	0.81	2.03	37.55	1.19	2.14	3.33	41.26	8.60	5.82	14.42	53.03
Sodium nitrate, 2 parts; ammonium sulfate, 2 parts...	0.77	1.32	2.09	36.64	0.65	3.60	4.25	40.91	5.22	9.35	14.57	51.84
Sodium nitrate, 3 parts; ammonium sulfate, 1 part....	0.40	1.51	1.91	35.94	0.33	3.76	4.09	38.46	2.83	14.58	17.41	52.26
Urea............	0.61	0.68	1.29	29.07	1.06	1.12	2.18	36.29	—	—	—	—

*Tops and rice combined.

produced with urea and the best growth of rice with the 3 to 1 ratio of nitric and ammoniacal nitrogen. Nitric nitrogen was apparently assimilated much better and ammoniacal nitrogen more poorly during the second stage, as is indicated by the fractions of these forms present at the end of the second stage. The toxic action of the ammonium ion had by this time become strongly evident on wheat and, to a less extent, on rice.

Third stage.—For the groups of plants which were carried through three stages of growth, the 3 to 1 combination of nitric and ammoniacal nitrogen proved the most productive of dry matter. Sodium nitrate alone was the second best source of nitrogen for wheat and the 2 to 2 combination of nitric and ammoniacal nitrogen the next best for rice. During this stage the cumulative toxicity of ammonium sulfate had become very pronounced for wheat and so great for rice that their growth was practically inhibited in the solution of ammonium sulfate alone and in that containing 2 parts of ammoniacal nitrogen to 1 part of nitric nitrogen. The degree of toxicity in the two species of plants closely paralleled the milligrams of ammoniacal nitrogen present at the end of the third stage.

In the early part of the first stage of growth a chlorosis of the rice plants set in in all cultures. This condition was particularly marked on plants in sodium nitrate and urea cultures, but was corrected for all cases except the solutions containing urea by increasing the concentration of ferric potassium tartrate from 5 to 25 p. p. m. Complete recovery of the plants grown in urea was never effected, and this condition probably was a factor in causing them to die before the completion of the third stage. Wheat showed no chlorosis under the same conditions, which indicates a somewhat higher iron requirement for rice than for wheat.

SUMMARY

Varieties of wheat and lowland rice were grown in complete nutrient solutions supplied with different chemical forms of nitrogen. Sodium nitrate, ammonium sulfate, and urea and combinations of sodium nitrate and ammonium sulfate to furnish nitric and ammoniacal nitrogen in the ratios of 1 to 3, 2 to 2, and 3 to 1 were used to supply chemically equivalent amounts of nitrogen. The plants were harvested in three growth stages and dry weight of plants and certain nitrogen fractions in the plants were determined.

Both species of cereals assimilated all forms of nitrogen to a certain extent. On the whole, rice was more at home with ammonium sulfate than was wheat. Both kinds of plants assimilated nitrogen from ammonium sulfate better in the early stages than in the later stages of growth. The best growth of rice in all stages of growth was obtained with the 3 to 1 ratio of nitric and ammoniacal nitrogen and of wheat with the same ratio except that in the second stage urea gave the greatest weight.

Toxicity of ammonium sulfate was more pronounced with wheat than with rice, and this toxicity increased with the age of the plant. The toxic effect rather closely paralleled the amount of ammoniacal nitrogen found in the plants.

Rice exhibited a much higher iron requirement than did wheat.

BOOK REVIEWS

HANDBOOK OF CHEMISTRY

Edited by Norbert Adolph Lange, assisted by Gordon M. Forker, and with an appendix of mathematical tables and formulas by Richard Stevens Burlington. Sandusky, Ohio: Handbook Publishers, Inc. XIV+ 1545 pages. Fabricoid. $6.

This volume is the most complete of its kind which has come into the hands of the reviewer. In spite of its many pages, it is extremely compact and usable due to the light weight paper and flexible cover. The typography is well done and exceptionally clear. The arrangement of tabular matter is very comprehensive and a splendid index makes it easy of access. The scope of the volume is remarkable, meeting needs of not only workers in many fields of chemistry but also of the physicist, mineralogist, and engineer. Workers in foods and vitamins, alloys, dyes, and sanitation as well as the bio-chemist are not forgotten.

The book proper deals with no less than 160 different subjects for tabulation. Besides the tables there are comprehensive expositions of such subjects as the occurrence, properties, uses, and discovery of the chemical elements; chemical, photographic, and engineering formulas and equations; glossaries of chemical, pharmaceutical, and ceramic terms; methods of hydrogen-ion determination; and outlines for qualitative analysis and laboratory arts and recipes. Gravimetric factors alone cover 22 pages and conversion tables another 36 pages.

The appendix of 250 pages presents formulas and theorems for algebra, geometry, trigonometry, and calculus besides tables of logarithms, interest tables, and many others.

Many features are new. To cite only a single example, besides the physical constants of several thousand inorganic compounds, the book also gives those for no less than 4,450 selected organic compounds each with its Beilstein reference. The book is not only of great value to the chemist or engineer but would seem almost indispensable to the worker having difficult access to a technical library. (R. C. C.)

DER LÖSS UND SEINE GEOTECHNISCHEN EIGENSCHAFTEN

By Dr. -Ing. Alfred Scheidig. Dresden and Leipzig: Theodor Steinkopff. XII + 233 pages, illus. 1934. Paper RM 18; cloth RM 20.

This book, with an introduction by Professor Dr.-Ing. F. Kögler, is a comprehensive treatise on the loess materials of the world. The subject matter is presented from the geological, the physical, and the engineering and technical points of view.

The book is made up of three parts. Part 1 deals with the geology and the geographical distribution of loess. Under this heading are discussed the nature of true loess, the distribution of loess over the earth, loess and landscape, the origin of loess, the soils of the loess groups, and the importance of loess to mankind. Part 2 is concerned with the physical properties of loess. It approaches the subject from the standpoint of composition, texture, sedimentation, structure, density, pore space, absorption, water action, permeability, plasticity, cohesion, elasticity, frost action, and physical methods of classification. Part 3, the largest section of the book, is given over to the geotechnical aspects of loess. It treats of the construction of roads, bridges, canals, and railroads in loess territories; of drainage and other water relationships; and of the technical uses of the material.

The book is well illustrated by means of graphs, maps, and photographs. An extended bibliography is attached. An exposition as comprehensive as the present work could hardly be expected to be exact in every detail. The reviewer questions the accuracy of the distribution of loess in the United States as it is shown on the map on page 21. The boundaries appear to extend too far, both to the east and to the west. But, should this be an error, it is of minor importance when one considers the scope of the volume and the wealth of material which lies between its covers. The author has made a valuable contribution to the subject in its many phases, the result of years of research and consulting work in the loess districts of Germany, Russia, Austria, and Hungary. (B. D. W.)

FELLOWS ELECT

JOHN HUNTINGTON PARKER

JOHN HUNTINGTON PARKER, Kansas State College, Manhattan, Kansas. Born at St. Paul, Minn., Aug. 13, 1891. B.S., University of Minnesota, 1913; M.S.A., Cornell, 1916; Ph.D., Cambridge, 1928. Scientific Assistant, Cereal Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1913–17; Prof. Crop Improvement, Kansas State College, 1917—; Acting Professor, Cornell, 1931–32.

Member A.A.A.S.; American Society of Agronomy; Genetics Society of America; Kansas Academy of Science. Special interests: Disease and insect resistance in cereals, inheritance in wheat, oats, barley, and sorghum.

Prof. Parker is a member of the committee on varietal standardization and registration and has made important contributions to the field of crop improvement.

FREDERICK DAVID RICHEY

FREDERICK DAVID RICHEY, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Born at St. Louis, Missouri, September 3, 1884. B.S.A., University of Missouri, 1909. Scientific Assistant, Assistant Agronomist, Agronomist, Senior Agronomist, and Principal Agronomist, 1911–1933, and in charge of corn investigations, 1923–1933, Bureau of Plant Industry; Associate Chief and Chief, Bureau of Plant Industry, 1934—.

Member A.A.A.S.; American Society of Agronomy; Society of Plant Physiology; Statistical Association; Genetics Society of America; Botanical Society of Washington; Washington Academy of Sciences; Cosmos Club of Washington. Special interests: The breeding, genetics, and growth of maize, and statistical methods for interpreting research data.

Mr. Richey has served on several special committees of the Society, as a leader of a symposium on corn improvement, and as a contributor to the annual programs of the Society. He has been a leader in the development of methods of corn breeding.

ROBERT MUNDHENK SALTER

ROBERT MUNDHENK SALTER, Ohio State University, Columbus, Ohio; Ohio Agricultural Experiment Station, Wooster, Ohio. Born at Huntington, Indiana, March 31, 1892. B.S.A., Ohio State University, 1913; M.S., 1914. Assistant Soil Chemist, West Virginia Agricultural Experiment Station, 1916–1917; Soil Chemist, 1917–1919; Agronomist, 1919–1921; Assistant Professor Soil Chemistry, College of Agriculture, West Virginia University, 1917–1919; Professor of Agronomy, 1919–21; Professor of Soils, Ohio State University, 1921–1925; Chief Agronomist, Ohio Agricultural Experiment Station, 1925—; Chairman, Department of Agronomy, Ohio State University, 1929.

Member of A.A.A.S.; American Society of Agronomy; American Soil Survey Association; International Society Soil Science. While his special interests include field plat experiments, fertilizers, and fertilizer placement, he is also much interested in all other phases of agronomic work.

Professor Salter has served on many special and standing committees and is chairman of the Committee on Fertilizer Distributing Machinery. He has been a frequent contributor to the program of the annual meetings of the Society.

FELLOWS OF THE AMERICAN SOCIETY OF AGRONOMY

The following persons have been elected Fellows of the Society during the 10 years that this special recognition has been extended for distinguished service in agronomy.

1925

C. R. Ball
J. G. Lipman
T. L. Lyon
M. F. Miller
R. W. Thatcher*
L. E. Call
C. A. Zavtiz
C. E. Thorne
P. E. Brown
S. B. Haskell
C. W. Warburton
C. V. Piper*

1926

B. L. Hartwell
H. H. Love
C. A. Mooers
Emil Truog
C. G. Williams

1927

F. J. Alway
T. A. Kiesselbach
A. G. McCall
R. A. Oakley*
H. K. Hayes

1928

C. F. Marbut
A. J. Pieters
George Roberts
Oswald Schreiner
A. T. Wiancko

1929

W. L. Slate
H. L. Shantz
E. F. Gaines

1930

F. S. Harris
J. A. Bizzell
W. P. Kelley

1931

W. W. Burr
M. A. McCall
C. F. Shaw
F. D. Gardner
W. H. Stevenson

1932

A. B. Beaumont
Andrew Boss
M. J. Funchess
S. C. Salmon
F. T. Shutt

1933

R. I. Throckmorton
R. J. Garber
A. R. Whitson

1934

J. H. Parker
F. D. Richey
R. M. Salter

*Deceased.

MINUTES OF THE TWENTY-SEVENTH ANNUAL MEETING OF THE SOCIETY

The twenty-seventh annual meeting of the Society was called to order by President R. I. Throckmorton at 9:00 a. m. on Thursday, November 22, at the Wardman Park Hotel in Washington, D. C. The general program was given at this session. The annual dinner featuring the address of the President, after which the business session of the Society was held, occurred on Thursday evening. The Crops Section and the Soils Section held meetings on Thursday afternoon and on Friday. About 350 members and visitors attended the various sessions.

The president appointed an auditing committee consisting of the following: Prof. C. E. Millar, *Chairman*, and Prof. J. C. Russel. He also announced the nominating committee of which the President of the Society is Chairman, according to the Constitution, and two members of which are appointed by the Chairman of the Crops Section and two by the Chairman of the Soils Section. The committee consisted of President Throckmorton, *Chairman*, F. D. Keim, H. N. Vinall, A. L. Patrick, and J. G. Hutton.

COMMITTEE REPORTS

EDUCATION IN AGRONOMY

Prof. A. L. Patrick presented the report of the Committee on Education in Agronomy, which, upon motion, was adopted and the Committee discharged, with the understanding that a Section on Teaching be organized which will occasionally hold a program at the annual meeting of the Society. The report of the Committee is as follows:

The Committee on Education in Agronomy made a study during the latter part of the year of the distribution of occupations of those men who have received bachelors, masters, and doctors degrees in agronomy during the 4-year period from 1931 to 1934, inclusive. The study was made to determine the extent to which the men who have recently received their degrees have been appointed to positions. The occupations listed are for those held during the late summer of 1934.

The response to the questionnaires submitted to the Land Grant Colleges and Universities throughout the United States was gratifying, 46 of the 48 institutions responding. Of these, 10 stated that their undergraduate students do not specialize. A total of 36 institutions reported on men who had received their bachelor's degree, 34 on men who had received their master's degree, and 15 on men who had received their doctor's degree (Table 1).

TABLE 1.—*Distribution of occupations in 1934 of men who received their degrees in agronomy during the 4-year period 1931–34.*

Degree	Number of schools reporting	Number of men receiving degrees	Percentage of men who are											
			Farming	Doing experimental work	Teaching in colleges or universities	Teaching in secondary schools	Teaching in high schools	In extension service	On agricultural relief projects	In commercial work related to agriculture	In non-agricultural work	Doing graduate work	Unemployed	Unaccounted for or deceased
Bachelor's	36	834	15.1	11.0	2.2	1.1	15.6	10.3	18.6	7.2	5.4	9.3	2.0	2.2
Master's	34	275	3.2	31.6	6.5	1.9	7.6	8.7	19.3	7.6	2.2	9.4	0.7	1.1
Doctor's	15	104	0.0	40.4	28.8	0.9	0.0	3.8	19.2	4.8	0.0	0.0	1.9	0.0

The 36 institutions reporting on men who received their bachelor's degree graduated a total of 834 men. Of this number, 126, or 15.1%, are farming; 92, or 11.0%, are doing experimental work; 18, or 2.2%, are teaching in colleges and universities; 130, or 15.6%, are teaching in high schools; 155, or 18.6%, are engaged in agricultural relief work of some type, such as soil erosion, rehabilitation, and water conservation projects; 77, or 9.3%, are doing graduate work; 60, or 7.2%, are engaged in commercial work related to agriculture; and 17, or only 2.0%, are unemployed. This distribution of graduates differs from that of the preceding 5 years primarily in a smaller percentage of the men being engaged in farming, in experimental work, and in commercial work related to agriculture and in a fairly large percentage being engaged in some form of agricultural relief work. It is encouraging to learn that only 2% of the men receiving bachelor's degrees in agronomy during the last 4 years are unemployed.

Nineteen of the 36 institutions reported that more than 10% of the graduates are farming, 12 reported that more than 20% are farming, and 2 reported that more than 30% are farming. Seven institutions reported that no graduate of the last 4 years is engaged in farming.

In 12 of the institutions reporting, more than 10% of the graduates of the last 4 years are doing experimental work; at 6 of them more than 20% are doing experimental work; and at only 3 are more than 30% of them engaged in this field. No graduates from 9 of the institutions are doing experimental work.

With four exceptions, all of the institutions reported that one or more of their graduates of the last 4 years are engaged in agricultural relief work. A much higher percentage of the graduates from southern institutions than from those of the north are employed on agricultural relief projects.

Records for men receiving their master's degree were received from 34 institutions. These institutions granted the master's degree to 275 men during the 4-year period. Only 9 of these men are farming, while 87, or 31.6%, are engaged in experimental work; 18, or 6.5%, are teaching in colleges and universities; 24, or 8.7%, are engaged in extension service; 53, or 19.3%, are working on agricultural relief projects; and 26, or 9.4%, are doing graduate work. Only two were reported as being unemployed.

The 15 institutions which reported on men who have received their doctor's degree showed that a total of 104 men have received this degree during the last 4 years. No one from this group is engaged in farming; 42, or 40.4%, are doing experimental work; 30, or 28.8%, are teaching in colleges and universities; and 20, or 19.2%, are working on agricultural relief projects. Two of the men from this group are reported as being unemployed.

It is encouraging to note the high percentage of men who have received the bachelor's, master's and doctor's degrees in agronomy during the last 4 years who are gainfully employed at this time.

W. H. DARST A. L. PATRICK
E. R. HENSON R. I. THROCKMORTON,
CLYDE MCKEE *Chairman*

FERTILIZERS

Dr. A. B. Beaumont presented the report of the Committee on Fertilizers, which was adopted as follows:

Within the past year this Committee has prepared a report entitled, "The Determination of the Relative Requirements of Crop Plants for each Fertilizer Ingredient". The limitations and possibilities of this type of work are pointed out, a procedure is outlined, and suggestions for standardization of method and technic are offered in this report which is printed below.

Recently considerable interest has developed in the question of acid and basic potentialities of commercial fertilizers on the part of both agronomists and fertilizer producers. The Association of Official Agricultural Chemists is particularly concerned with this question, since it is the body which must set up analytical standards by which a fertilizer is to be judged as to its potential effect on soil reaction. It appears that the problem must be considered from an agronomic as well as a chemical standpoint. Therefore, the National Fertilizer Association has, through its Fertilizer Committee, requested the Fertilizer Committee of the American Society of Agronomy to give the agronomic aspects of the problem prime consideration during the coming year. With this in view we request that this Committee for the ensuing year be reconstituted so as to include in its membership those agronomists who are particularly interested in this problem and have facilities for greenhouse work.

We wish to call the attention of the Society also to another development in technic which has a bearing on the use of fertilizers. We refer to the comparatively rapid, recent development of methods for diagnosing plant nutrient deficiencies in soils. On the basis of such diagnostic methods recommendations for the use of fertilizers are made. A brief survey of the situation in the principal fertilizer-consuming sections shows that thousands of soils are being tested annually in some states with these rapid chemical methods. A good many agronomists are convinced that certain helpful information is gained by such tests. The manufacture and sale of equipment for conducting these tests is an attractive field for the unscrupulous, and instances of impossible claims for equipment and methods are not unknown. The possibilities of exploitation of farmers, gardeners, and homemakers in this field are obvious. In view of all this, the Society may wish eventually to set up some machinery looking toward a standardization of methods of this character.

THE DETERMINATION OF THE RELATIVE REQUIREMENTS OF CROP PLANTS FOR EACH FERTILIZER INGREDIENT

Introduction.—The problem of determining the fertilizer requirements of crop plants is complicated by the existence of many factors which affect organic growth. Some of these can not be controlled in field experiments. In addition, practical considerations demand that attention be given such economic factors as cost of fertilizer and value of crop. Besides these, there are factors which have both agronomic and economic bearing, such as type of cropping system, methods of soil management, and kind of fertilizer used.

The following examples bring out the variety of conditions under which the agronomist must work in attempting to determine the fertilizer requirements of crops: On a strongly acid soil a high-nitrogen fertilizer with ammonium salts as the source of nitrogen may be decidedly injurious, whereas on a neutral soil the same fertilizer may have an opposite effect; in the Connecticut Valley it is common practice to grow tobacco continuously on the same field and to use 3,000 to 4,000 pounds of high grade fertilizer per acre, while in the south tobacco is usually grown in rotation with other crops and with ⅛ to ¼ as much fertilizer as is used in the Connecticut Valley; the Florida vegetable grower uses fertilizer to the point of maximum production, while grain farmers of the Middle West use a modicum of fertilizer, but make use of legumes as catch or rotation crops.

It is obvious, then, that our problem is exceedingly complicated, but it is none the less important on account of its complexity. After careful study of this problem this Committee has concluded that it would be impracticable to outline in any great detail a standard procedure for determining fertilizer requirements of crop plants, which would be applicable to any considerable extent. However, the Committee wishes to express in the following statements its opinion relative to the limitations and possibilities of this type of experimentation.

Limitations and possibilities.—1. It is futile to attempt to determine the most suitable ratio, grade, or quantity of fertilizer required for any given crop unless one can define, (a) the type of soil; (b) the kind of fertilizer materials; (c) the cropping system; (d) the frequency with which legumes are grown and manures applied; (e) the reaction of the soil; (f) other factors known to affect plant growth.

2. At present the most that can be hoped for in determining the fertilizer requirements of crop plants is to determine the relative response to the several fertilizer constituents for a given set of conditions and that is both possible and desirable.

3. Attempts to draw fine distinctions in response to fertilizer elements will prove disappointing. Usually, it will be better to make gross rather than small differences in the quantities of nutrients supplied.

Outline of procedure.—In its simplest form, a procedure for determining the relative response of crop plants to fertilizer nutrients consists of growing two or more crops side by side, fertilized with mixtures containing *high*, *medium*, and *low* amounts of the element under consideration, and optimum fixed quantities of the other nutrients. It is desirable, also, to have treatments in which the variable element is omitted, in order to prove whether it is needed at all.

This simple outline is illustrated by the following example: For a given crop and set of conditions, an agronomist assumes that a given acre rate of 2-12-6, 8-12-8 (figures refer to percentage of N, P_2O_5, and K_2O, respectively), or any other grade of fertilizer will supply optimum quantities of any two nutrients. This grade will be designated as the optimum grade. It may constitute, then, either the medium or low grade in the fertilizer series. *High*, *medium*, *low*, and *zero* grades will then be as follows (taking the 8-12-8 as an example):

	N series	P_2O_5 series	K_2O series
High	12-12-8	8-18-8	8-12-12
Medium	8-12-8	(8-12-8)	(8-12-8)
Low	4-12-8	8-6-8	8-12-4
Zero	0-12-8	8-0-8	8-12-0

This simple plan requires a minimum of 10 plats. Replications may be made as many times as conditions demand and permit. Usually, experimental field error may be expected to decrease with increase of replications up to 5.

Suggestions for standardization, technic, etc.—1. Soil type. Experiments should be made on the most representative and extensive soil type suitable for the crops grown.

2. Crops. In the selection of crops, first choice should be given those important in other states as well as locally. The following are suggested: corn, cotton, tobacco, wheat, oats, potatoes, sorghum, cabbage, lettuce, and soybeans. An early yellow dent corn is suggested as a standard for comparison in all experiments.

3. Fertilizers. The fertilizer ratio best suited to the needs of a particular crop under a given set of soil and climatic conditions will depend, in part, upon the materials selected to supply the several nutrient constituents. For that reason, it appears desirable to use several carriers of each of the three commonly mentioned fertilizer constituents plus enough limestone to make the net effect of the mixture on the soil approximately neutral. It is suggested, therefore, that the nitrogen be supplied one-third each from the ammonium, nitrate, and urea forms of nitrogen; the phosphoric acid, one-third each from superphosphate, treble-superphosphate, and ammonium phosphate; and the potash, one-third each from the muriate, sulfate, and nitrate forms of potash.

4. Lime, etc. Use sufficient lime to bring the reaction of the soil to what is considered the best for the crops used. For most crops this will be between pH 6.0 and 6.5, but there are execptions. If there is reason to suspect a deficiency of magnesium in the soil, supply this in the form of dolomitic lime or limestone, magnesium sulfate, or some other suitable carrier. Also, make provision for supplying rare elements such as manganese, zinc, copper, etc., if a deficiency is suspected.

5. Cropping systems. Follow the cropping system best suited to the crops in question. This may be continuous or rotation cropping. Alternate or criss-cross cropping has its advantages from the standpoint of promoting uniformity, etc. It may be desirable in some cases to grow cover or catch crops in order to maintain soil organic matter.

6. Technic. It is neither possible nor desirable to prescribe details of technic. For such questions as size and shape of plat, the agronomist is referred to the 1933

report of the Committee on Standardization of Field Experiments (Jour. Amer. Soc. Agron., 25:803–828, 1933).

H. J. HARPER
B. L. HARTWELL
F. E. BEAR
F. C. BAUER
A. B. BEAUMONT,
Chairman

FERTILIZER APPLICATION

Prof. R. M. Salter presented the report of the Joint Committee on Fertilizer Application, which was adopted as follows:

The Committee on Fertilizer Distributing Machinery has continued to function as one of the constituent sub-committees of the National Joint Committee on Fertilizer Application. During the past year, under the sponsorship of the Joint Committee, machine fertilizer placement investigations were carried on at 54 locations in 19 states, and involved the following crops: Cotton, corn, potatoes, sugar beets, tobacco, tomatoes, cabbage, and snap, lima, and white beans. Detailed reports of these studies will be published in the Proceedings of the Tenth Annual Meeting of the Joint Committee on Fertilizer Application which may be obtained from H. R. Smalley, Secretary of the Joint Committee.

The machine placement experiments with corn, cotton, and potatoes have progressed to the point of permitting rather definite conclusions as to proper placement and machine design. Marked improvement has already been made in fertilizer distributors on commercial corn and potato planters and new machines have recently been developed for planting and fertilizing cotton in a single operation, the fertilizer being placed in the desired position with respect to the seed. Progress has also been made in the development of improved fertilizer distributors on transplanting machines. A gratifying amount of new work has been undertaken during the year on the placement of fertilizers on vegetable crops.

In addition to the fertilizer placement studies, a number of experiments were conducted in which physiologically acid and neutral fertilizers were compared on cotton and potatoes. It is the opinion of the committee that a more extensive coordinated program of research on fertilizer reaction should be undertaken during the coming year.

It is recommended that the committee be continued.

C. O. ROST
J. J. SKINNER
EMIL TRUOG
J. R. FAIN
H. B. MANN
ROBT. M. SALTER,
Chairman

PASTURE RESEARCH

Chairman H. N. Vinall presented an abstract of the report of the Joint Committee on Pasture Research, which was adopted as follows:

FOR TAME PASTURES IN HUMID OR IRRIGATED SECTIONS

I. Grazing experiments.
   1. The experiments should be located on a uniform soil type representative of large areas of grazing land in the section served by the experiment station.
   2. The unit grazed by one group of animals should be large enough to support preferably six animal units and in no case less than four. On variable soils, a unit one-third as large replicated three times, with the replicates grazed in rotation by *all* the animals, is preferable to a large single unit.
   3. Rectangular paddocks in which the length is 3 or 4 times the width are preferable to square paddocks.

4. Experimental paddocks should be securely fenced.
5. In general, the livestock used should be that kind most abundant in the section served by the experiment.
6. Male animals, after they are castrated, are preferable to females.
7. Fairly mature growing animals are better for grazing studies than very young or very old ones.
8. Handling livestock on experimental pastures:
    (a) The average capacity for production either of meat or milk should be as nearly equal as possible in the various groups.
    (b) A given group of animals should not be shifted from one experimental area to another unless rotational grazing is being investigated.
    (c) Individual weights should be obtained on three successive days at the beginning and end of the grazing season. Intermediate weights once every 28 days are sufficient. All weights should be taken at the same time of day, preferably in the morning.
9. Supplemental feeding during the grazing season should be avoided as far as possible especially in fertilizer experiments. At least 75% of the animals' feed should be obtained from grazing.
10. The use of supplemental pastures in lieu of supplemental feeds during periods when the experimental pastures are inadequate is recommended.
11. In all grazing experiments, the *rate* of grazing should be indicated, not as cow-days or sheep-days but as unit-days per acre. This is not to be considered as the final measure of production. It seems probable that an adjustment of the number of animals on any paddock from time to time to conform to the growth of herbage is desirable in order to insure that each paddock is grazed at the optimum rate.
12. Production of the different plots or paddocks should be recorded in total digestible nutrients calculated from the T. D. N. required for maintenance of the animals plus the T. D. N. indicated for the gains in weight and (or) the milk produced. If supplemental feed or supplemental grazing are provided, the T. D. N. represented by these additions should be subtracted from the total. If a value is to be placed on the production of T. D. N., the feed replacement plan is perhaps best suited to this need because feed values change not only with the years but during a single season.
13. Measuring pasture yields by agronomic methods:
    (a) Beside the measurement of the production of grazed plots by the T. D. N. computed from the effect on the grazing animal, it is desirable to measure the yields by mowing representative areas protected from grazing. There are two methods for arriving at yields in this way. One attempts to measure the quantity of herbage *consumed* by the grazing animals; the other measures the annual growth of herbage or that available for grazing. In measuring the herbage *consumed*, plots of convenient size and replicated at least three times in each experimental area are protected by wire cages or movable fences and clipped at regular intervals at least as often as the cattle are weighed. An unprotected area of the same size and representative of the herbage left by the cattle is clipped at the same time and the yield subtracted from that of the protected area. Each time a clipping is made the cage or fence is moved to a new area and the process repeated. The total of these remainders should closely approximate the quantity of herbage eaten by the grazing animals.

   (b) In measuring the herbage *available* for grazing an area of the same size as that to be protected will be clipped and the yield recorded. The cage or fence is then placed on this clipped area and at the end of the chosen interval the protected area is clipped again, after which the cage or fence is moved to a new position on which the grass has just been clipped. The sum of these clippings of mowed areas will indicate the season's growth of herbage, and this added to the spring clipping equals herbage *available* for grazing during the season, but not necessarily all eaten.

   (c) In both systems, areas which have remained ungrazed should be avoided in locating the cages.

14. All yields should be stated on a dry-matter basis. This may be determined by taking a representative composite sample of the clippings from the three or more replications and reducing this sample to a moisture-free condition. Such samples are then used in the chemical studies of the herbage.
15. A knowledge of the composition of the herbage from the various grazing units is useful, although not indispensable. Where a feed-stuff analysis of the samples is made, it should be in accordance with methods adopted by the American Association of Official Agricultural Chemists. In many cases a determination of the calcium and phosphorus content of the herbage is equally to be desired.
16. Information on the digestibility of pasture herbage is of immediate importance and further digestion trials with animals on pasture are recommended to our associates in Animal Husbandry. For present purposes the report of the American Dairy Science Association that the dry matter of pasture herbage is 72% digestible may be accepted for computation of T. D. N.
17. A botanical survey of the plant population in tame pastures should be made at least once each year and preferably in both spring and fall. On native pastures annual surveys and on some kinds bi-ennial surveys are adequate. The method of making such surveys properly varies with the kind of pasture under investigation, and several methods are described in the complete report of this Committee.
18. Grazing experiments should be continued 8 or 10 years in order to ascertain the effect on the turf as well as to obtain a fair average of favorable and unfavorable seasons.
19. Certain contingent or contributing data should always be presented with the grazing results, such as:
    (a) Previous history of the pasture area.
    (b) Information as to the soil type and uniformity.
    (c) Records of any soil amendments applied, with quantity and date of application.
    (d) If irrigated dates and quantity of water applied.
    (e) Condition of pastures and date grazing began each year.
    (f) Rainfall distribution and amount compared with normal.
20. Cost data from experimental pastures are of little value except for comparison of different methods within the experiment itself, such as the cost of supplemental feed combined with pasturage compared with feed obtained wholly from grazing; or the additional cost of fencing required for rotation grazing compared with that needed for continuous grazing. The cost of materials, with the possible exception of fertilizers, and operating costs are

always excessive when calculated from small plots. Cost data, if given, should be calculated on the average cost per acre of each operation, such as fencing, applying fertilizer, clipping, and harrowing on fields containing at least 40 acres.

A. E. Aldous	George Stewart
B. A. Brown	Paul Tabor
L. F. Graber	H. N. Vinall, *Chairman*

SOIL EROSION

Chairman H. H. Bennett presented the report of the Committee on Soil Erosion, which was adopted as follows:

During the past year, the Federal Government inaugurated, through the Soil Erosion Service, the first large-scale, coordinated program for prevention and control of the evil of accelerated soil erosion ever undertaken in this country.

The Soil Erosion Service was created in the Department of the Interior to administer Public Works funds in a practical program of erosion prevention and control. Work of organization was commenced shortly after August 25th, 1933, and field work some weeks later, with an initial allotment of $5,000,000. This was subsequently increased to $10,000,000. Recently an additional $10,000,000 was made available, bringing to $20,000,000 the amount allocated to this type of work.

Because of the enormity of the far-flung problem of erosion, it was decided in the case of crop lands, to restrict the initial work to strategically located demonstrational watershed projects, the areas being selected on a regional basis and with due regard for representative soils, rainfall, topography, type of agriculture and prevailing conditions with respect to erosion. Each of these regional projects is intended to furnish a complete demonstration of coordinated and proper-balanced methods of land use and erosion control, specifically adapted to the needs of the various kinds of land. The program is characterized by a synthesis of procedure, involving the use of all proven methods of prevention and control in accordance with the most effective practical application of each, with undue emphasis given to none.

Thirty-two of these watershed projects have been selected so far, and of these 25 are underway in 27 states. A slightly different type of work is being carried out on the Navajo Indian Reservation and on the Federally-controlled land in the Gila River watershed of Arizona and New Mezico.

The method of procedure in the demonstration watersheds involves the application to every acre of land such measures of prevention and control as are needed to maintain productivity and to increase the absorption of rainfall. All work is carried out strictly in cooperation with property owners and operators, who are required to sign cooperative agreements effective for five years, under which they contribute labor and materials to the extent of their ability, modify their farming practices in accordance with the plans of the Soil Erosion Service and take out of cultivation to clean-tilled crops specified critically erosive areas where it is impracticable to control erosion in any other way. In return for this sooperation, the Soil Erosion Service effects the necessary planning, furnishes technical supervision and supplying such labor and materials as the co-operator is unable to contribute. It is estimated that, on the average, the cooperating farmers contribute from about 30 per cent to 50 per cent of the cost of the work.

The work is carried on in cooperation with various Federal organizations and with the state colleges of agriculture, through advisory councils and by direct contact with the extension, crops, forestry and engineering specialists of the state institutions.

The detailed procedure on a typical watershed is as follows:

1. A good aerial photographic map is made of the entire watershed, the individual photographs being enlarged to a scale of 1 inch equals 500 feet. These enlargements are sufficiently clear in detail to show all timber and pasture areas, most field boundaries, the principle details of gully erosion, and even sheet erosion in those regions where the topsoil and the subsoil are of distinctly contrasting colors.

2. Using the aerial photographic enlargements as a base, detailed land classification surveys are made of the entire area, with the individual farm ordinarily constituting the working unit. These surveys show the distribution by fields of the major types of land, the slope variance, the degree of erosion and the susceptibility of cultivated, forested and grassed areas to erosion. Where the conditions warrant, a record is also made of the condition of the soil with respect to acidity and alkalinity.

With these physical facts in useable form, each farm unit within the watersheds is carefully gone over on the ground by the staff specialists in company with the farmer, and practical, applicable plans for the stabilization of all erosive areas are developed, due consideration being given to the economic requirements of the individual farms. These plans are then incorporated in the five-year cooperative agreement mentioned above.

3. Following the signing of the cooperative agreement, the actual work of controlling erosion begins. Such methods as strip cropping, terracing, scarification of the land, interrupted furrowing, rearrangement of fields to permit contour cultivation and the practice of crop rotation, seeding, liming, fertilizing and other farm procedures necessary to establish effective soil conservation are put into effect under the supervision of the best trained specialists obtainable. Skilled agronomists and foresters proceed with the task of planting the steeper and more erosive lands, eliminated from cultivation, to the most adaptable types of erosion-resistant crops, such as grass, clover, lespedeza, sorghum, etc., and to trees. Plans for practical fire control and the prevention of over-grazing are also worked out and put into effect. Where there are possibilities of developing a return from land retired from cultivation, through the development of game resources, specialists in this field prepare and put into operation programs for developing such wild life as may prove profitable to the farmer through opportunity for sale of hunting privileges. Under the limitations of the present program, this work is, of course, confined to those areas where the methods of game rehabilitation involve the planting of erosion-resistant plants.

Land which has been hopelessly eroded is, in some instances, left to revegetate to volunteer growth. Frequently, the recuperation of such areas is quite rapid with the aid of effective fire protection. In other instances, the regulation of grazing suffices. Many badly eroded areas require special treatment in the form of simple check dams supported by plantings of trees, grasses and vines adapted to gully conditions. For example, rapidly expanding gullies in the central prairie states can be quickly and completely controlled by the planting of black locust. Gullies of smaller magnitude have been economically controlled by placing across them old fertilizer sacks filled with fertile earth and the seeds or roots of adaptable grasses. The grasses puncture the sacks and their roots rapidly extend into the ground, usually establishing such effective barriers as completely to control the gully.

As of October 21, 1934, 789,732 acres had been covered by signed cooperative agreements. Under the plans called for in these agreements, more than 20 per cent of the cultivated acreage is to be retired from cultivation, 27 per cent is to be strip-cropped, 27 per cent is to be planted to erosion-resistant crops, 59 per cent is to be farmed on the contour and 47 per cent is to be terraced. There will be a decrease of 15 per cent in the acreage of clean-tilled crops.

The largest projects are on arid and semi-arid Federally-controlled lands in the far West: One on the Navajo Indian Reservation, comprising 24,500 square miles, and the other on the Gila River watershed of Arizona and New Mexico, involving approximately 8,000 square miles.

In these two projects are found practically all of the serious problems facing the grazing and irrigation civilization of the Southwest. The Navajo Indian Reservation involves a critically serious condition of accelerated upland erosion resulting from over-grazing, together with progressive cutting away of productive valley fills by gullying, accompanied by lowering of the water table, transformation of perennial streams into ever-broadening flood channels, and general desiccation of the region. The products of this accelerated process of land degradation will enter the Boulder Dam Reservoir. The stabilization of this area presents a most difficult and challenging problem. For success, it is not only necessary that over-grazing be controlled and that necessary mechanical and vegetative measures be installed for gully control, and that vegetation be restored to the ranges; but it is necessary also to reorientate the entire economy of the 45,000 Navajo Indians living in this area, most of whom speak neither English nor Spanish. In order to reduce the over-grazing, assistance must be furnished toward the development of other sources of income and food supply. This calls for considerable effort in the direction of transforming a predominantly nomadic grazing people to a semi-agricultural status; and for the encouragement of supplemental income-producing activities. Thus, on the Navajo project (including the Hopi and Zuni lands) the Soil Erosion Service, in cooperation with the Bureau of Indian Affairs, is faced with a complete job of regional, sociological and economic planning and execution.

The work on the Navajo Reservation involves land-classification surveys and the application of adaptable land-use measures developed therefrom, as well as the operation of a demonstrational experiment station (covering a complete watershed of approximately 70 square miles) in order to work out new methods of prevention and control and to improve old methods.

The Gila River project presents still another phase of the problem of erosion control in the Southwest. Here is a large watershed, drained by a river which, according to available evidence, formerly carried a perennial flow relatively free from silt, and which was not subject to excessive flooding. The land comprised within this watershed for the most part consists of public domain. Part of it lies within national forests and part within Indian reservations, with only 3 per cent in private ownership. The public domain and Indian reservation lands have suffered severely from erosion because of over-grazing. The Gila River has been converted into one of the worst flood torrents of the country, and many thousands of acres of irrigated lands are being cut away along both sides of its course. In places the channel has been widened from 10 to 20 times during the past 60 years. Vast quantities of silt are being deposited in the Coolidge Reservoir, thus undermining the security of the San Carlos irrigation project.

During the past winter with an allotment of 1,000 men from the Civil Works Administration, the Soil Erosion Service demonstrated within a period of four working months that it is practicable to carry out much effective erosion-control work in this region. With the abandonment of all Civil Works projects, work was suspended. Later in the year, an allotment of five CCC camps was obtained and work resumed. Recently, the Gila River area has been approved as a major watershed project of the Soil Erosion Service, and the necessary land-classification surveys and engineering studies of flood-control detention reservoirs are getting under way.

Another activity of the Soil Erosion Service relates to its cooperation with the National Resources Board in the presentation of pertinent data relating to the national erosion situation and plans for a far-reaching control program. During the year a reconnaissance erosion survey of the entire United States was completed. Every county in the country was examined, the force employed amounting to 115 men. The findings of this survey are summarized below:

Reconnaissance Erosion Survey of the United States

Different Erosion Conditions	Acres
Area covered by survey	1,924,650,100
Area showing little or no erosion	540,059,617
Area affected by erosion in some degree	1,384,590,483
Area from which ¼ to ¾ of topsoil removed by water erosion	575,317,688
Area from which ¼ to ¾ of topsoil removed by water and wind erosion	645,670,041
Area from which more than ¾ of topsoil and some subsoil removed by water erosion	201,725,519
Area from which more than ¾ of topsoil and some subsoil removed by water and wind erosion	214,264,093
Area affected by gullying	938,746,352
Area moderately gullied	503,041,357
Area severely gullied	425,736,488
Area destroyed by gullying	9,968,507
Total area affected by wind erosion	311,347,709

OTHER AGENCIES WORKING ON EROSION

Among other agencies now working on erosion is the Emergency Conservation Work organization. One hundred and ninety-nine erosion camps have been established. Of these, 51 are supervised by the Soil Erosion Service and are working on its regularly established projects. The remaining 148 camps are administered by the United States Forest Service, working almost entirely on private lands under the general supervision of state agencies, with field supervision furnished by engineers. This work is largely confined to gully control.

The Federal Emergency Relief Adminsitration has sponsored a wide-spread terracing program in some of the southern and mid-western states. This program apparently contemplates the construction of terraces as a single implement for controlling erosion.

The Extension Service has continued with its program of terracing work in many counties, including instruction in laying off and building terraces and other activities in this direction.

The year 1934 has seen a tremendous effort put forth to control excessive runoff and erosion of the soil. As this work continues the importance of vegetation in connection with prevention and control of erosion is becoming increasingly evident.

Its use is not only effective and economical, but it is natural and, therefore, the most logical way for effective lasting results. Once established and managed consistently, vegetation is far more permanent than any other method yet devised. This is strikingly exemplified on countless steep slopes where native vegetation has maintained the gradient and checked erosion for centuries, permitting at the same time the development of a normal soil profile.

The work of the 10 erosion experiment stations established by the U. S. Department of Agriculture, under the supervision of the Bureau of Chemistry and Soils, continues to show that under many conditions erosion can be enormously reduced or almost completely controlled with adaptable measures involving vegetative cover. For example, the results of four years' work at the Guthrie Experiment Station show the effectiveness of vegetation in controlling runoff and soil losses on the very important Vernon fine sandy loam. Although the results vary somewhat in detail from place to place, in general the same trend holds at all of the erosion stations throughout the United States.

Effect of type of vegetation in controlling runoff and soil loss at the Red Plains Soil Erosion Experiment Station, Guthrie, Oklahoma. Four-year summary of soil and water losses, 1930–1933. Average rainfall 33 inches.

Type of vegetation	Slope	Runoff per cent	Erosion, tons per acre
Cultivated row crop (cotton)	7.7	14.0	26.7
Small grain (wheat)	7.7	13.2	1.8
Hay (sweet clover)	7.7	9.2	.72
Native woods (burned)	5.2	5.1	.22
Grass (Bermuda sod)	7.7	1.5	.04
Native woods (Virgin)	5.2	.14	.02

During this period the runoff from row crops has been nearly 10 times as much as from a field in Bermuda sod. The soil loss has been 668 times as great. Small grain although but little more effective than row crops in checking runoff is decidedly effective in reducing soil loss. Burned woods lost 36 times as much rainfall as did the unburned woods and about 11 times as much soil. These data show conclusively that close-growing vegetation is nearly 100 per cent effective in checking soil and water losses under the conditions prevailing in the vicinity of Guthrie. However, in general agricultural practice it is necessary to grow inter-tilled crops as well as dense vegetation. The results at all of the soil erosion experiment stations have shown high soil and water losses for all row crops when grown in the ordinary way. Since it has been shown that native or dense vegetation is highly effective in preventing erosion, the real problem is the development of methods of growing row crops with a minimum of soil and water losses.

Among the various methods that have been shown to be effective in reducing these losses may be mentioned crop rotation, fertilization, contour farming, terracing, strip cropping with or without terracing, and certain modified cultural practices, such as listing, use of the basin or hole-digging cultivator, etc. The value and effectiveness of such controls are being checked up as rapidly as possible.

At Guthrie, Oklahoma the value of using proper crop rotations is shown where cotton grown in a three-year rotation with wheat and sweet clover lost an average of 15.9 tons per acre annually as compared with cotton grown continuously which lost an average of 28.1 tons per acre. At Bethany, Missouri, corn grown continuously lost 61.2 tons of soil per acre, while corn grown in rotation lost 33.8 tons.

These data show the effect of one factor alone in reducing soil loss. In 1932 two plots which were in corn in the same rotation, except that one plot was treated with lime and phosphate, showed a loss of 19.16 tons for the untreated plot and 9.8 tons for the treated.

These data indicate that if crop rotation and fertilization were combined with contouring, strip-farming, terracing, etc., the losses could be still further reduced and brought down to a reasonable minimum without undue dependence on a particular control procedure, which frequently may of necessity involve extremes in order to take care of a given situation.

Of particular interest and importance in the development of the work of the year are the results obtained through infiltration studies. The striking differences, as between soil types, that have been obtained in these studies point to the importance of their application in establishing the type of erosion control measures best fitted to a given soil. It is the present hope that this work can be advanced rapidly during the coming year.

A. B. Conner H. H. Krusekopf
F. L. Duley H. H. Bennett,
Chairman

STUDENT SECTIONS

Dr. R. H. Walker presented the report of the Committee on Student Sections which was adopted as follows:

The committee on Student Sections of the American Society of Agronomy wishes to report that student sections have been organized in Nebraska, Illinois, Minnesota, Iowa, Kansas, and Oklahoma. A recent report from these sections gives a total of 114 members. The sections as organized are as follows:

Illinois—Ernest Riley, *President;* Robert Eckhardt, *Vice-President;* Harold Garwood, *Secretary-Treasurer.*

Minnesota—John Larson, *President;* L. H. Schnnesing, *Secretary-Treasurer;* Chester Graham, *Manager.*

Iowa—Horace Cheney, *President;* Oren Bolin, *Vice-President;* Derald Langham, *Secretary;* Albert Klingebiel, *Treasurer.*

Kansas—Frank G. Parsons, *President;* Lewis Evans, *Secretary;* George Rogler, *Treasurer.*

Oklahoma—Olen Zolduske, *President;* Richard Potts, *Vice-President;* Armer Fielder, *Secretary-Treasurer.*

Each section has designated a representative to meet in Chicago in connection with the Crops Judging Contest. At this meeting the representatives will plan a program for a half day session at the next annual meeting of the American Society of Agronomy in Chicago, and will perfect the organization.

The essay contest has not received the support that its merit would seem to justify. The committee feels that an effort should be made to enlarge the prizes from outside sources and further efforts should be made to stimulate interest in the contest through teachers of agronomic subjects.

Essays this year were judged by Dr. H. K. Wilson of Minnesota, A. L. Frolick of Nebraska, and John B. Wentz of Iowa. The results of the contest were as follows: First prize, "Plant Improvement," Derald Langham, Iowa State College, $15.00 and one year's subscription to the Journal of the American Society of Agronomy; second prize, "Production Reduction as a Means of Improving Iowa's Soil," Oren E. Bolin, Iowa State College, $10.00 and one year's subscription to the

JOURNAL; and third prize, "Can the Soybean Take It?" Paul L. Poirot, University of Illinois, one year's subscription to the JOURNAL.

The committee plans to publish news notes of the student sections as soon as organization is completed.

A. L. FROLICK G. H. DUNGAN
H. K. WILSON E. R. HENSON,
J. W. ZAHNLEY *Chairman*

STANDARDIZATION OF STATISTICAL NOTATIONS

Prof. F. R. Immer presented the report of the special Committee on Standardization of Statistical Notations, which was adopted as follows and the committee discharged:

In view of the rather wide usage of different symbols to designate the same statistic, it would seem desirable to attempt some standardization of notation. The Committee feels, however, that it would be wise to proceed slowly in recommending but one symbol for each statistic in common use. Conditions will arise requiring new methods and new uses of present statistics and flexibility of notation is essential. The dangers inherent in setting up too rigid a system of notation are very great.

One of the real sources of difficulty experienced by some workers engaged in agronomic research seems to be due to their lack of familiarity with statistical methods. Another difficulty lies in the seeming multiplicity of symbols used by different authors of statistical text books. Both of these conditions are beyond the control of the Committee.

In the case of manuscripts which deal essentially with research in statistics the Committee feels that the author will be qualified to use a notation that fits in with his objectives. It is urged, however, that the author follow, insofar as possible, symbols in common use and exercise great care in defining clearly the meaning of each symbol used.

It is recommended that the number of items be designated by n and the degrees of freedom (d.f.) by $n-1$, $n-2$, etc. The separate variables may be designated as x, y, etc., and the respective arithmetic means by $\bar{x}$, $\bar{y}$, etc. For standard deviation either s or σ is suggested and for summation either S or Σ satisfies the conditions of good usage. Standard errors of the mean, difference, or sum may be designated by appropriate subscripts.

It is recommended that the use of the probable error be abandoned and the standard error be used to replace it. The standard error is being used more and more frequently in American literature and is used almost exclusively in Europe. The use of both probable error and standard error tends to confuse rather than clarify the situation.

R. J. GARBER L. J. STADLER
J. T. MCCLURE F. R. IMMER,
F. D. RICHEY *Chairman*

PUBLICATIONS OF THE SOCIETY

Dr. C. W. Warburton reported for the Committee on Publications of the Society. The report was adopted as follows:

The Committee on Publications has had no formal meeting during the year, but has discussed certain matters in correspondence between themselves and with the Editor. The recommendation of the Committee, fixing the maximum length for papers and the charge to authors for excess pages, has brought satisfactory results, as indicated by the report of the Editor.

The Editor's inquiry with reference to possible subscription to an annual volume of proceedings did not result in sufficient responses to justify further consideration of the matter at this time. Dr. Lipman's effort to obtain outside funds to defray part of the cost of publication of such a volume has not been successful.

In view of the Editor's report that the accumulated manuscripts for publication have been cleared up, and that prompt publication in the JOURNAL can now be assured, there would appear to be no present need for further consideration of publication of a separate volume of proceedings.

J. G. LIPMAN
J. D. LUCKETT, *ex officio*
W. L. SLATE
C. W. WARBURTON, *Chairman*

RESOLUTIONS

Prof. F. D. Keim presented the report for the Committee on Resolutions, which was adopted as follows:

Following the procedure established with the appointment of a standing committee on Resolutions, your committee has continued, as one of its functions, to take note of the death of agronomists who have long been active in their lines of work.

It is with sorrow and a feeling of great loss that we must record the deaths since the last meeting of the Society of R. W. Thatcher, Massachusetts State College, Amherst, Mass.; W. B. Cobb, North Carolina State College, Raleigh, N. C.; A. H. Meyer, University of Louisiana, Baton Rogue, La.; and Karl F. Kellerman, U. S. Dept. of Agriculture, Washington, D. C.

A statement regarding the life and work of these men is made a part of this report, with the exception of Dr. R. W. Thatcher concerning whom a brief note was published in the December, 1933, number of the JOURNAL.

WILLIAM BATTLE COBB

William Battle Cobb, Professor of Soils at North Carolina State College, was the son of Mary Battle and Collier Cobb. He was born at Cambridge, Mass., on November 23, 1891.

His boyhood was spent in Chapel Hill, N. C. He attended Warrenton High School, Warrenton, N. C. He received his A.B. degree from the University of North Carolina in 1912 and his A.M. degree in 1913. From 1911 to 1913 he was assistant in Botany at the University. In 1927, Dr. Cobb received his Ph.D. degree in Geology from the University of North Carolina. From 1913 to 1918 he was with the U. S. Dept. of Agriculture in soil survey work.

He entered the world War in 1918 and was Lieutenant in the Air Service of the United States Army from 1918 to 1919, and at the time of his death he held a commission as First Lieutenant in the Air Service Reserves.

From 1919 to 1920 he was in soil survey work with the federal government. In 1920, with W. A. Davis, he made a soil survey of Tyrrell County, North Carolina. In this survey he used an aeroplane for mapping the large inaccessible areas of this county. This was a pioneer use of the aeroplane in soil survey work.

During the summer of 1920 he was geologist and soils specialist for the American Rural Planning Association of Wisconsin. From 1920 to 1924 he was Associate

Professor of Agronomy in charge of Soils at Louisiana State University. Dr. Cobb came to North Carolina State College in 1924 as Head of the Soils Department where he remained until his death. In 1926, he was on the American Organizing Committee of the First International Congress of Soil Science, and in 1932 he was President of the American Soil Survey Association.

During the summers of 1923 and 1924 he taught soils and geology in the University of North Carolina. The summers of 1930 and 1931 were spent in soil survey work in the Middle West, and the summer of 1928 was spent in soil survey work in North Carolina.

Dr. Cobb married Miss Eva Cahoon of Columbia, N. C., on December 28, 1920. He is survived by his wife and three children, Mary Martha aged 11, Carol aged 10, and William Battle, Jr., aged 5.

Dr. Cobb was one of the foremost soil scientists in the world and an authority on the soils of North Carolina. This is even more significant in view of the fact that North Carolina probably has more different soil types than any state in the Union.

Dr. Cobb's name is listed in *American Men of Science* and in *RUS*, a biographical register of rural leadership in the United States and Canada.—C. B. WILLIAMS.

KARL FREDERIC KELLERMAN

Karl Frederic Kellerman was born on December 9, 1879, at Göttingen, Germany, where his parents were in temporary foreign residence. He died in Washington, D. C., on August 30, 1934. He grew up at Manhattan, Kans., and Columbus, Ohio, where his father, the distinguished botanist, W. A. Kellerman, was successively Professor of Botany in Kansas State Agricultural College and Ohio State University. Doctor Kellerman received his collegiate training at Ohio State and Cornell Universities, graduating from the latter institution in 1900. In recognition of his scientific accomplishments, he received the degree of doctor of science from Kansas State College in 1923.

Immediately after graduation, Dr. Kellerman was appointed assistant in botany at Cornell University, remaining there for one year when he entered the Bureau of Plant Industry of the U. S. Dept. of Agriculture as assistant physiologist in 1901. In the Bureau he advanced by successive stages to positions of greater research responsibility. His research in water supply purification and in soil bacteriology produced results of great practical importance and value.

In 1914 he became Assistant Chief of the Bureau of Plant Industry, and in 1917 Associate Chief. In these positions he exerted an influence that will long be felt not only in the Bureau of Plant Industry, but also in the Department as a whole. He assisted in organizing and establishing the *Journal of Agricultural Research* in 1913, and for 10 years was chairman of its editorial committee.

Beginning in 1914, he served as a member of the Federal Horticultural Board and took an active part in formulating national plant quarantine policies and procedures. He himself organized and directed the successful research and regulatory program which resulted in the complete control of the citrus canker disease which threatened such widespread disaster to the American citrus industries. He also organized and directed the phony peach disease eradication program of the Department, and pushed it forward to its present satisfactory status. Probably more than any other one man, Dr. Kellerman played a dominant part in developing modern concepts of plant disease quarantine and control procedures, and he certainly played a most important part in successfully organizing and putting these concepts into effect. His assignment in 1934 to the leadership of the plant disease eradication and control program of the Bureau of Entomology and Plant Quarantine, which position he held at the time of his death, was a well-merited recognition of his leadership in this field.

Entirely apart from his official influence, Dr. Kellerman exerted a very great personal influence on the research of the Bureau of Plant Industry. Those who were so fortunate as to seek his advice and counsel in their research problems will never forget the stimulation of his keen, active mind and the multitude of suggestions arising from comprehensive knowledge and from his appreciation of the interrelationships of what often seemed to be totally different fields of science. Doctor Kellerman was ever generous of his time and help to the younger scientists of the Bureau, and conferences with him on scientific problems were always a revelation to the younger staff members. His ideals and standards and the effect of his dynamic personality and inspiration will long be felt in the Bureau of Plant Industry.

One of his characteristics which those who knew Dr. Kellerman best most admired, was his unswerving courage. If he believed in a given policy and felt that it should be put into effect, he unswervingly held for it, no matter how difficult its realization. The high standards and place of the Bureau of Plant Industry in American scientific work directly reflect that courage.

Doctor Kellerman was a long-time member of the American Society of Agronomy and took an active interest in its work. He was a member of the American Association for the Advancement of Science (Fellow), the Washington Academy of Science, International Society of Soil Scientists, Society of American Bacteriologists, Botanical Society of America, American Society of Naturalists, Biological Society of Washington, Botanical Society of Washington, and Sigma Xi. He also was a member of Delta Upsilon and of the Cosmos Club of Washington.—M. A. McCall.

ALFRED H. MEYER

Dr. Alfred H. Meyer, Regional Director of the Soil Erosion Service and Associate Research Professor of Agronomy, Louisiana State University, Baton Rouge, La., died in the Hospital at Minden, La., September 15, 1934, from injuries received in an automobile accident. Dr. Meyer was a passenger in the car and at the time of the accident was apparently not seriously hurt, but it developed a few hours later that he had received a skull fracture which surgical treatment could not relieve. He was born at Grafton, Wisconsin, in 1888, received the B. S. A. degree from the University of Wisconsin in 1911, took the Civil Service Examinations of the U. S. Dept. of Agriculture, Bureau of Chemistry and Soils, and entered the Soil Survey in 1911.

Dr. Meyer continued in the soil survey work for nine years. He had charge of the soil survey work in Nebraska for four years during which time he also did graduate work at the University of Nebraska and in the winters mapped soils in Louisiana, Texas, Mississippi, Alabama, South Carolina, and Arkansas. In 1917 he was put in charge of the soil survey work of the U. S. Dept. of Agriculture in Iowa where he remained for four years except for surveying in the southern states during the winters. He resigned from the Soil Survey of the U. S. Dept. of Agriculture in 1920 and took charge of soil surveying for the University of Georgia for two years.

Dr. Meyer pursued graduate studies at the University of Wisconsin from 1924 to 1927 and was granted the Ph.D. degree by that institution in June, 1927. He was a member of the Country Life Club, Alpha Zeta, Phi Sigma, and Sigma Xi fraternities. His most notable research at the University of Wisconsin was on methods for the colorimetric determination of phosphorus and the influence of the more rare nutrient elements, especially manganese and iodine, as factors in plant growth. Dr. Meyer then went to the State Agricultural and Mechanical College of South Carolina, Clemson, S. C., as Associate Research Professor of Soils. After two years at Clemson, he came to Louisiana State University as Associate Research Professor of Agronomy and Soil Technologist.

Dr. Meyer made very important contributions in advancing the soil fertility studies of the Louisiana Agricultural Experiment Stations. So well recognized was his knowledge of the soils and soil problems of Louisiana that he was chosen in 1934 by the Soil Erosion Service of the U. S. Dept. of Interior as Regional Director of the Louisiana projects. At the same time, the Louisiana State University, being reluctant to lose his valued services, still held him as a Research Professor on leave.

Dr. Meyer's unpretentious manners and his careful and scholarly attack of problems which was born of the highest degree of native intelligence and an inherent love for the soil and those who must live close to it, endeared him and his work to his many associates and friends. He was keenly interested in all scientific development and an active member of the A. A. A. S. and of the International Society of Soil Science.—M. B. STURGIS.

E. F. GAINES
S. B. HASKELL
G. E. RITCHEY
J. D. LUCKETT, *ex-officio*
F. D. KEIM, *Chairman*

LAND UTILIZATION

Dr. J. G. Lipman presented the report of the Committee on Land Utilization which was adopted as follows:

In submitting this brief report, the Land Use Committee would note that within the past twelve months notable progress has been made in land use planning in the United States. Federal, regional, state and local agencies have made important contributions on the subject. Reference may be made to the following.

1. As reported by Dr. L. C. Gray: "The most significant development in Federal policy has, of course, been the definite inauguration of a land use program by the Federal Government. The more important aspects of this program to date have been the provision of funds for the purchase of submarginal land, establishment of the National Resources Board, and the establishment of the Agricultural Adjustment Administration of the Division of Program Planning and of the Land Policy Section as a part of that Division."

The outline of the report on land utilization and policies conveys definite information on the scope of the important work that has been carried out under Dr. Gray's direction. The broader topics dealt with in the land use report, which is to be released by the President in the near future, include those of general conditions and tendencies influencing the Nation's land requirements for the various major uses; land requirements in relation to land resources, for the Nation as a whole; and maladjustments in land use and in the relation of our population to land and proposed lines of action. Under these major topics, such subjects are dealt with as outlook for population; industrial conditions; tendencies toward mechanization as affecting the human requirements in agriculture; present use of the land surface and summary of recommended uses; agricultural land requirements and resources; forest land requirements and available resources; recreational requirements; requirements for wild life areas; land required for the use of the Indians; requirements for other uses; and land in non-urban areas, e. g. city water supplies and reservoirs, irrigation and power reservoirs, etc.

It is noted further by Dr. Gray that an initial allotment of $25,000,000 of P. W. A. funds was made for the purchase of submarginal land. In addition, the Deficiencies Bill carries an authorization of $50,000,000 for the acquisition of land in the drought area. A portion of this fund has already been allocated. The Federal Emergency Relief Administration, with the cooperation of the National Park Service, the Office of Indian Affairs, the Bureau of Biological Survey and the Land Policy Section, has made definite plans for the use of large areas of submarginal land. The Division of Rural Rehabilitation of the Federal Emergency Relief Administration has set up definite projects for the resettlement, or rather rehabilitation of farm families located on submarginal land areas.

The following may also be quoted from a recent statement by Dr. Gray. He says: "The basic function of the Land Policy Section is the development of a coordinated long-time national program for the better use of our land resources, the program to include not only the formulation of plans and policies, but also the carrying of these plans and policies into a definite program of action in the various states. In addition, the Section has also agreed, at the request of the Federal Emergency Relief Administration, to plan and develop specific submarginal land acquisition projects under the allotment of funds referred to above. Another significant development has been the passage of the so-called Taylor Act for regulated grazing on the public domain up to a total of 80,000,000 acres. This represents an important step forward."

2. The 11th Circular Letter, dated May 15, 1934, of the National Planning Board is entitled "Studies of City and Regional Planning in the United States." This is an important contribution on the subject of regional planning with all the major implications of land use for urban and other purposes.

3. An inventory of the soil resources of the United States has been completed by Dr. F. C. Marbut and his coworkers. Tables have been prepared which record by states the acreages of the various classes of land. In referring to this tabular matter, Dr. Marbut notes that it constitutes an inventory of the land of the United States. As he puts it: "The lands of the whole country have been differentiated into 5 units, defined on the basis of their relative natural inherent productivity of the land for the dominant crops of grains and grass, mainly corn, wheat, oats, barley, grass and hay grown under ordinarily approved good methods of treatment and without irrigation or the addition of fertilizers other than the use of crop residues and the growth of legumes in the rotation or other correctives. It represents the productivity of the natural soil after a few years of cultivation from its virgin state during which what may be called *virgin fertility* residing in the accumulated thin layer of assimilated organic matter in the surface layer." He says also that "The rating is based on actual crop growing experience in the United States obtained practically, exclusively by the Soil Survey Staff in 30 years of soil and crop production studies in the field in all parts of the United States. . . . . Through these long time studies of the relation of crop yields to soil, climatic and relief features the optimum environmental conditions for the dominant crops have been determined. A basis for land rating is thus established by means of which the inherent capacity of a tract for crop production may be determined wholly independently of statistical data but on the basis of soil, climatic and relief features."

4. The Federal Forest Service is in a position to report some outstanding accomplishments. In a recent letter, the Acting Forester, Dr. E. A. Sherman, notes

the following: "One of the principal achievements of the year was the development of the forest section of the Land division of the report of the National Resources Board. The survey of all counties or appreciable parts of counties of which 50 per cent of the area is actual or potential forest land was conducted by the Forest Service. The study covered 1,758 counties or appreciable parts of counties and a gross area of 890,000,000 acres, or almost half the land area of the forty-eight states. It was participated in by the State agencies concerned with the conservation of the natural resources, e.g. State Planning Boards, State Conservation Departments, State Foresters, State Universities, etc., the results representing the composite thought, or concensus of opinion, of those agencies. In consequence, the report will present both a broader and a more detailed picture of the extent and condition of the forest lands of the United States than any hitherto formulated."

Aside from the survey just referred to, the Forest Service contributed information concerning the administration and plans for the protection and development of our national forests, on the harmonization of the various uses of forest lands. The factors of stable community life, industrial development, economic security, employment potentialities, and many others received helpful consideration. The guiding thought in the formulation of forest land use has been the treatment of and dealing with our forest resources in such fashion as to conserve our forest capital and draw on the increment of growth as corresponding to interest returns rather than the using up of our forest capital through destructive liquidation.

5. A Soil Erosion Service has been set up in the Department of the Interior and placed under the administrative direction of H. H. Bennett. The following may be quoted from a recent communication submitted by Dr. Bennett.

"The National Resources Board is preparing a statement on a national program of planned land-use. Many purchase areas of steep and non-arable land have been designated for Forestry uses, and a number of national parks have been specified. The acquisition of extensive areas of marginal and submarginal lands and their dedication to adaptable uses for growing trees and grasses, marks a stride in the correct utilization of lands that were once good farms but which have been worn out by erosion.

"The establishment, organization and operations of the Soil Erosion Service marks the highlight of practical progress during the past year in the field of soil and moisture conservation and wise land-use in connection with the administration of the nation's agricultural resources.

"The broad program comprehends the extension of essential erosion control measures and improved farm practices to all the eroding farm lands of the nation. Initial procedure has been to establish large watershed demonstrations, in line with the President's suggestion on that point, where representative agricultural systems are being dealt with and where the plan of work is essentially a coordinated program of correct land use.

"The genius of the program is that of assembling for each area demonstration, a staff of highly trained specialists representing all phases of agricultural research and practice, so that the problem of erosion may be attacked from every possible angle of approach. Each project organization includes specialists in soils, agronomy, agricultural engineering, farm management, erosion, farm economics, extension, forestry, and wild life, each group integrating its work into a well-rounded, comprehensive and coordinated working program. Revised farm practices are set up and lands are used and treated on the basis of their adaptibility and their needs.

"From the major demonstrations, as centers, distribution of small demonstrations, by counties, within respective zones of influence, will prepare the way for cooperative alliances among all available agricultural agencies for carrying the work to all individual farms.

"There are at present 30 major watershed demonstrations comprising approximately 27,000,000 acres of land in 27 states."

6. The chairman of your committee has been engaged in the study of the reserves of plant nutrients in the United States. A brief of the monograph which he is preparing on the subject was submitted to the National Resources Board. This particular study has to do with the inventory of plant nutrients in the various soil regions of the continental United States. In addition, consideration is given, by means of statistical treatment, to the various additions to the inventory, such as atmospheric precipitation, animal manures, crop residues, the fixation of nitrogen by legumes and non-symbiotic bacteria, chemical fertilizers, lime, industrial waste products, etc. Similar consideration is given to losses chargeable to erosion, leaching, removal of crops, removal of animals and animal products, the destructive decomposition of soil organic matter, etc.

The studies and compilations referred to above indicate that land use policies and problems in the United States have been dealt with in a most fruitful way. It is indicated, also, that a foundation is being laid for the more effective use of the greatest of our natural resources in behalf of national progress and well-being.

C. F. Marbut
R. S. Smith
G. W. Conrey
N. E. Winters
J. G. Lipman, *Chairman*

VARIETAL STANDARDIZATION AND REGISTRATION

Chairman M. A. McCall presented the report of the Committee on Varietal Standardization and Registration which was adopted as follows:

During the year the Committee registered five varieties of wheat, *viz.*, Relief, Rex, Rio, Sturgeon, and Thatcher, and three varieties of oats, *viz.*, Lenroc, Rusota, and Spooner. Descriptions of these varieties will appear elsewhere in the Journal.

Progress was made during the year in collecting the data for a list of standard cotton varieties, but this task entails so much in the way of study that it was not possible to complete it in time for the annual meeting.

Progress was also made in the preparation of standards for the registration of grain sorghums, but the submission of these plans has been held up pending the publication of necessary varietal descriptions for standard varieties. The relatively large number of new varieties meeting registration requirements is evidence that research activity in quality and crop improvement is being maintained in spite of many serious handicaps.

H. B. Brown
J. Allen Clark
E. F. Gaines
H. K. Hayes
W. J. Morse
J. H. Parker
T. R. Stanton
G. H. Stringfield
M. A. McCall, *Chairman*

OFFICERS' REPORTS

REPORT OF THE EDITOR

J. D. Luckett, Editor, presented the following report which upon motion was accepted and a vote of thanks extended by the Society to Mr. Luckett for his work on the JOURNAL during the year:

The time has come for the annual accounting to the Society of the status of its JOURNAL, and we are pleased to say at the outset that the accounting this year is going to make somewhat more agreeable reading than circumstances have permitted for the past few years.

To go back for a moment to this time last year, with its painful picture of frozen bank deposits, dwindling resources, the JOURNAL barely maintaining itself financially and dropping further behind in its publication schedule, you will recall that, through the Executive Committee, the Society authorized the Editor to put into effect certain changes in the management of the JOURNAL. Chief among these was the establishment of a limit on the number of pages available for free publication and the fixing of a charge for each additional page beyond this limit. Other departures from former practices included the discontinuance of free reprints and a lowering of the liability of the JOURNAL with respect to the cost of illustrations.

The elimination of free reprints and the decision to pass along to the author a larger share of the cost of making halftones and etchings were definitely designed to reduce the cost of publication. It was pointed out at the time, however, that charging for extra pages beyond the fixed maximum allowance should not be regarded as a source of revenue. Rather it was felt that it would discourage over-long contributions; and most of all, that it would provide a means whereby the unprecedented carry-over of papers at the beginning of 1934 might more rapidly be moved along to final publication. That the plan has accomplished the desired end will be evident later in this report.

It has been our practice to arrive at an understanding with the Treasurer at the beginning of the year on the number of pages that we might reasonably expect to pay for during the year in the light of collection of dues and the cost of printing as shown by each new contract with the printer. In line with this practice, it seemed to Dr. Brown and myself that we could safely proceed on the basis of publishing 80-page numbers of the JOURNAL during 1934. Having established 8 pages as the maximum allowance for free publication in the JOURNAL, this immediately gave us a sound basis upon which to project the year's publication schedule. It meant, for one thing, that each issue of the JOURNAL could carry at least ten papers, for if any of these papers exceeded the 8-page limit we knew that the added cost of publishing the extra pages would be met by the author. As a consequence, you will find that some numbers this past year carried twelve or fourteen contributed articles, exclusive of notes, book reviews, etc. Formerly, we would often be restricted to seven or eight papers per number if we were to keep within safe limits.

With the December number of the current volume in the printer's hands, except for the minutes of this meeting and the index for the volume, we can now give you a fairly definite accounting of our own "New Deal." There will be in the 1934 volume 134 contributed papers in addition to 10 book reviews, 13 notes, and numerous miscellaneous items that fall under the general heading of "Agronomic Affairs". We must go back to the 1927 volume of the JOURNAL to approach these figures and so far as we know they have never been equalled. There have been larger volumes of the JOURNAL, to be sure, for the 1934 volume will make less than 1,100 pages, but we doubt if any previous volume presents as great a variety of papers or will make as strong a demand for recognition, both at home and abroad, in the various lines of research which fall within the field of what we call "Agronomy".

You will be interested to know that of these 134 papers, 30 exceeded the 8-page limit by from 1 to 12 pages and that altogether 99 pages in the current volume have been paid for by the contributors.

We mentioned above that the chief objective of the new plan was to advance contributions more rapidly toward publication, and on this point we have so far surpassed our own expectations that we almost hesitate to make them public for fear every agronomist who reads this report will at once hunt out that paper that has been waiting for just such an opportunity, In our report at the annual meeting last year, we announced that we had on hand at that time 69 papers awaiting publication in 1934. Today we have but five papers to start off the January, 1935, issue.

It was rather disconcerting after all of these years to see for the first time the bottom of the manuscript drawer, a receptacle some 8 inches deep that usually is crammed to the top and overflows onto the floor whenever it is opened. But doubtless something will be done to remedy this situation, and that right speedily.

In looking ahead to 1935, we believe that, as regards the management of the JOURNAL, the Society might well continue along much the same lines as in 1934, despite the fact that the major objective, that is, the taking up of the slack in surplus manuscripts, has been largely attained. We were fortunate this year in consumating our contract with the printer prior to the final adoption by the graphic arts industry of its code prices. Our new contract will be exactly 32% higher, and we shall need to do everything possible to hold the advantage we have gained this past year if we are to fare as well in 1935. We are recommending to the Executive Committee, therefore, the same provisions for the coming year as for 1934, namely, a limit of 8 pages for free publication, a charge of $4 per page for each page beyond the 8-page allowance, no free reprints, and a $10 limit on illustrations.

Much of the credit for the successful working out of the new plan for the JOURNAL must go to the contributors themselves, who have cooperated wholeheartedly in bringing their papers into line with the ideas of the reviewers and the Editor. We are deeply grateful, too, to the several members of the Society who have aided us in reviewing manuscripts during the year. Their's is a thankless task, at best, but one that is absolutely essential to the success of the JOURNAL.

Last year the Committee on Publications gave some thought to a suggestion that the Society publish all of the papers presented at the annual meeting each year in a single volume. It was also suggested that the proceedings of the American Soil Survey Association might be incorporated in such a volume, providing the Association and the Society found the suggestion mutually agreeable. Obviously, the first consideration was that of cost of publication, as the volume would of necessity have to be financed entirely independent of the JOURNAL so far as our Society was concerned. The Committee on Publications, therefore, instructed the Editor to ascertain, as far as possible, the degree of interest on the part of members of the Society in the proposed volume, together with the probable financial support of the venture that might be reasonably expected.

We attempted to accumulate this information through notices in the JOURNAL and by means of a postcard which the members of the Society were asked to return if they favored the proposal. To date fewer than 10% of these cards have been returned to us, and since the venture would have to be self-supporting, it seems unwise to proceed further without more general interest in the undertaking. The fact, too, that the JOURNAL is now in a better position to handle contributions more expeditiously than was the case last fall when the proposed volume of proceedings was under discussion would seem to lessen the need at this time for an additional medium of publication with its added financial burden.

Here, then, is the status of the JOURNAL at the close of 1934. It is back on what we formerly regarded as a normal basis of a thousand pages per volume. There is an exceptionally small carry-over of papers. The interval between date of acceptance and date of publication of contributions has been reduced to the lowest point practicable in the printing of a monthly magazine. The cost of publication has been kept well within the capacity of the Society to pay. We are in a position to begin the new volume with a clean slate, financially and editorially, so to speak. It would seem, then, that we have reason to approach 1935 with optimism and confidence.

J. D. LUCKETT, *Editor*

REPORT OF THE TREASURER

The Treasurer presented the following report which was received and referred to the Auditing Committee:

I beg to submit herewith the report of the Treasurer for the year November 1, 1933, to November 1, 1934.

Total Receipts

Advertising income	$ 806.00	
Reprints sold	1,228.38	
JOURNALS sold	104.24	
Subscriptions, 1934	1,415.94	
Subscriptions, 1933	69.00	
Subscriptions, 1934, new	469.40	
Subscriptions, 1935	32.00	
Dues, 1934	3,150.46	
Dues, 1933	188.25	
Dues, 1934, new	428.60	
Dues, 1935	15.00	
Received on trust certificate	24.17	
Total receipts	$7,931.44	
Balance in cash, Nov. 1, 1933	27.38	
Total Income	$7,958.82	$7,958.82

Total Disbursements

Printing the JOURNAL, etc	$5,988.42	
Salary, Business Manager and Editor	799.72	
Postage (Secretary and Business Manager)	134.25	
Printing, miscellaneous	142.55	
Express on JOURNALS	63.72	
Mailing clerk	59.25	
Refunds, checks returned, charges, etc	44.60	
Miscellaneous expenses	214.80	
Total disbursements	$7,447.31	$7,447.31
Balance on hand, Nov. 1, 1934		$ 511.51
Balance in trust certificate		321.16
Total balance in account		$ 832.67
Balance in cash on hand	$ 511.51	

Respectfully submitted,
P. E. BROWN, *Treasurer*

REPORT OF THE ASSISTANT TREASURER

Dr. A. G. McCall, presented the report of the Assistant Treasurer, which was received and referred to the Auditing Committee:

AMERICAN SOCIETY OF AGRONOMY IN ACCOUNT WITH THE EXECUTIVE COMMITTEE OF THE FIRST INTERNATIONAL CONGRESS OF SOIL SCIENCE NOVEMBER 10, 1933, TO NOVEMBER 15, 1934

Receipts

Sale of Proceedings First International Congress of Soil Science (1927)		$ 74.00**	
Interest on savings account Prince George's Bank & Trust Company, Hyattsville, Maryland		64.24	
Exchange premium on check of $10.50 on Canadian Bank of Commerce, Victoria, B. C.		.26	
Outstanding checks:			
Check No. 434 Aug. 6, 1934	$1.00		
Check No. 436 Nov. 12, 1934	1.17	2.17	
Balance on hand in bank, savings account, Nov. 10, 1933		2,087.96	
Balance on hand in bank, checking account, Nov. 10, 1933		238.52	
			$2,467.15

Expenditures

Postage for office correspondence (transmitting deposits and membership records)	$ 20.00	
Rumford Press for handling and shipping sets of Proceedings	8.46	
Premium on bond for Dr. A. G. McCall, Ass't Treasurer	5.00	
Refund account overpayment on set of Proceedings to Ball & White, Bookshop	1.00	
Tax on checks (bank charge)	.10	
Balance on hand in bank, savings account Nov. 15, 1934 (This includes the contribution to Endowment fund of $1,000)	2,315.20	
Balance on hand in bank, checking account Nov. 15, 1934	117.39	
		$2,467.15

941 Sets of Proceedings on hand in storage with Rumford Press, Concord, N. H., as of Nov. 10, 1933

11 sets sold during the past year to and including Nov. 15, 1934

930 On hand in storage as of this date

Of the 11 sets sold	3 were sold at	$ 5.50
	1 was sold at	6.50
	5 were sold at	10.50
	2 were sold at	11.50
	1 Vol. I at	2.00

(sets billed and awaiting payment, 3)

Sets paid for

2 sets at $ 5.50 equals	$11.00
3 sets at 10.50 equals	31.50
2 sets at 11.50 equals	23.00
1 set at 6.50	6.50
1 Vol. I at	2.00
	$74.00**

Submitted by

A. G. McCall,
Exec. Secretary American Organizing Committee and Assistant Treasurer

AUDITING COMMITTEE

Prof. C. E. Millar, Chairman, reported that the Auditing Committee had examined the books and vouchers of the Treasurer and of the Assistant Treasurer and found everything correct and in order. The report was adopted.

REPORT OF THE SECRETARY

The report of the secretary was presented and accepted with appreciation, as follows:

I beg to submit herewith my report for the year.

The membership figures for the year are as follows:

Membership, last report			904
New members		89	
Reinstated		28	
Total increase		117	
Dropped for non-payment of dues	129		
Resigned	21		
Died	3		
Total decrease	153	153	
Net decrease		36	36
Total membership, November 1, 1934			868

The membership by states and countries is as follows:

Alabama	9
Arizona	11
Arkansas	6
California	38
Colorado	16
Connecticut	12
Delaware	3
District of Columbia	66
Florida	10
Georgia	9
Idaho	6
Illinois	37
Indiana	24
Iowa	35
Kansas	36
Kentucky	9
Louisiana	13
Maine	7
Maryland	16
Massachusetts	10
Michigan	15
Minnesota	21
Mississippi	7
Missouri	11
Montana	11
Nebraska	21
Nevada	1
New Hampshire	1
New Jersey	13
New Mexico	8
New York	37
North Carolina	15
North Dakota	13
Ohio	28
Oklahoma	13
Oregon	11
Pennsylvania	18
Rhode Island	7
South Carolina	8
South Dakota	9
Tennessee	7
Texas	33
Utah	10
Vermont	3
Virginia	18
Washington	16
West Virginia	9
Wisconsin	25

Wyoming	3
Hawaii	9
Philippine Islands	3
Africa	6
Argentine	6
Austria	1
Brazil	1
British West Indies	1
Canada	20
China	10
Cuba	2
Denmark	2
Egypt	1
England	2
Finland	1
Germany	4
Greece	1
Honduras	1
India	8
Italy	1
Japan	3
Jugoslavia	1
Mesopotamia	1
New Zealand	1
Palestine	1
Peru	1
Poland	1
Portugal	1
Spain	1
Sweden	2
Switzerland	1
Turkey	2
Uruguay	1
U. S. S. R. (Russia)	6
Total	868

The membership by years of election is as follows:

1908 Charter	28
1908	8
1909	3
1910	13
1911	21
1912	11
1913	14
1914	11
1915	17
1916	27
1917	11
1918	10
1919	11
1920	23
1921	32
1922	34
1923	22
1924	30
1925	60
1926	49
1927	40
1928	39
1929	73
1930	50
1931	55
1932	43
1933	43
1934	89
1935	1
Total	868

The total membership by years is as follows:

1908	121
1909	129
1910	176
1911	236
1912	295
1913	349
1914	397
1915	471
1916	586
1917	652
1918	509
1919	473
1920	436
1921	592
1922	643
1923	561
1924	577
1925	646
1926	700
1927	767
1928	823
1929	906
1930	943
1931	963
1932	949
1933	904
1934	868

The subscriptions figures for the year are as follows:

Subscriptions last report		530
New subscriptions	106	
Subscriptions dropped	98	
Increase	8	8
Subscriptions, November 1, 1934		538

P. E. BROWN, *Secretary*

FELLOWS

The Fellows-elect were announced by Vice-President H. K. Hayes and presented with diplomas (pages 1020 and 1021). Those receiving this honor were Professors John H. Parker, Frederick D. Richey, and Robert M. Salter.

CHILEAN NITRATE AWARDS FOR RESEARCH IN THE IMPORTANCE OF THE RARER ELEMENTS IN AGRICULTURE

Announcement was made of the acceptance by the Society of the administration of an annual award of $5,000 by the Chilean Nitrate Educational Bureau, for research in the importance of the rarer elements in agriculture. A committee will be appointed by the new President of the Society to draw up the regulations governing the making of the awards.

ANNUAL DINNER

The annual dinner of the Society was held on November 22 at 6:30 p. m. at the Wardman Park Hotel. Professor R. I. Throckmorton delivered the address of the retiring President at this time (pages 981 to 985).

REPORT OF NOMINATING COMMITTEE

The report of the Nominating Committee was made by H. N. Vinall, and upon motion the following officers were declared elected for the coming year: R. M. Salter, Vice-President; W. A. Albrecht and T. A. Kiesselbach, representatives of the Society on the Council of the A. A. A. S. H. K. Hayes automatically succeeded to the Presidency and R. D. Lewis was announced as elected Chairman of the Crops Section and C. E. Millar as Chairman of the Soils Section.

P. E. BROWN, *Secretary*

OFFICERS OF THE SOCIETY FOR 1935

President
H. K. HAYES, St. Paul, Minn.

Vice-President
R. M. SALTER, Wooster, Ohio

Chairman, Crops Section
R. D. LEWIS, Columbus, Ohio

Chairman, Soils Section
C. E. MILLAR, East Lansing, Mich.

Secretary-Treasurer
P. E. BROWN, Ames, Iowa

Editor
J. D. LUCKETT, Geneva, N. Y.

AGRONOMIC AFFAIRS

MINUTES OF THE 1934 BUSINESS MEETING OF THE CROPS SECTION

R. G. Wiggans called the business meeting of the Crops Section to order at 1:15 p.m., Thursday, November 22, at the Wardman Park Hotel, Washington, D. C.

The nominating committee, R. J. Garber, L. E. Thatcher, and M. A. McCall, *Chairman*, nominated R. D. Lewis of Ohio State University as Chairman of the Section and N. A. Pettinger of the Virginia Agricultural Experiment Station and H. B. Sprague of the New Jersey Agricultural Experiment Station as members of the program committee for 1935. On motion of L. E. Thatcher, seconded by H. K. Hayes, these nominations were unanimously adopted by the Section. There being no further business, the Section adjourned.—C. J. WILLARD, *Secretary*.

PUBLICATION OF PROCEEDINGS POSTPONED

With less than 10% of the readers of the JOURNAL expressing interest in the publication of a volume of Proceedings to contain the papers presented at the Annual Meeting and with the greatly improved condition of the JOURNAL with respect to accumulated manuscripts, it has been decided to abandon the idea of a volume of Proceedings for the present. This decision was approved by the Editorial Advisory Committee, the Committee on Publications, and the Executive Committee.

For the first time in recent years, the Editor is in a position to encourage members of the Society to submit papers for consideration for publication in the JOURNAL. Heretofore, the delays in publication have discouraged contributors somewhat, but the Editor will now welcome the opportunity to see more papers reporting on new work in agronomy and can promise prompt publication, at least for the present.

CANADIAN SEED GROWERS' ASSOCIATION REPORT

The 1933-34 annual report of the Canadian Seed Growers' Association is now off the press and may be obtained through the Association at 336 Jackson Building, Ottawa, Canada. In addition to the summary of the proceedings of the annual meeting of the Association held at Macdonald College, Quebec, in June, the report contains the recommendations to the Association from the Dominion Conference of plant breeders, reports of provincial directors and local branches, and the minutes of the annual meeting of the French Section of the Association held at the Oka Agricultural Institute at La Trappe.

NEWS ITEMS

THE ANNUAL dinner of the American Soil Survey Association held at the Wardman Park Hotel in Washington, D. C., on November 20 was made the occasion of a testimonial to Dr. C. F. Marbut who was presented with a gold watch.

R. H. MORRISH, Assistant Professor of Farm Crops at Michigan State College, has been transferred to the Extension Division and will have charge of sugar beet extension projects. He replaces C. R. Oviatt, who recently resigned to accept a position with the Sugar Section of the Agricultural Adjustment Administration.

Dr. STEPHEN T. DEXTER, formerly of the University of Wisconsin and more recently National Research Council Fellow, has been appointed Research Associate and Assistant Professor of Farm Crops at Michigan State College.

Prof. G. B. MORTIMER of the Department of Agronomy, University of Wisconsin, died on November 18.

Dr. J. G. LIPMAN was awarded the Chandler Medal in Chemistry for 1934 by Columbia University recently. The award was made in recognition of Dr. Lipman's "outstanding achievements in the field of agricultural chemistry."

FREDERICK D. RICHEY has been named Chief of the Bureau of Plant Industry, U. S. Dept. of Agriculture, to succeed Dr. K. A. Ryerson who becomes head of the section of sub-tropical horticulture.

A SERIES of symposia to commemorate sixty years of the modern era in botanical sciences was arranged by the Department of Botany of Iowa State College, including among other subjects "Erosion Prevention Capacity of Plant Cover" and "Applied Botanical Research of Maize."

THE ANNUAL fall mixer of the Iowa Section of the Society was held on October 24 in the Modernistic Dining Room of the Memorial Union, Iowa State College. New members of the section and graduate students were special guests.

THE IOWA STATE COLLEGE farm crops judging team won first place at the National Intercollegiate Crops Judging Contest held October 22 in connection with the American Royal Stock Show at Kansas City. The team scored 4,991 points, 6 points higher than the Nebraska team which took second place. Of the three members of the team, Albert Klingebiel was high individual of the contest and Derald Langham and Oren Bolin placed third and eighth, respectively, among the 24 individual records.

DR. DEAN BURK of the Bureau of Chemistry and Soils spent the last two weeks in October at Iowa State College giving a series of lectures on the metabolism of Azotobacter. These lectures were sponsored by the combined seminars of the Soils, Bacteriology, and Biophysical Chemistry Departments. While at Ames, Dr. Burk also delivered an address before the Iowa State College Chapter of Sigma Xi on "Photosynthesis in Wheat and Algae".

AT THE regular meeting of the Student Section of the American Society of Agronomy at Iowa State College held on October 25, Dr. W. G. Murray of the Agricultural Economics Department discussed "The Soil Type as an Index of Land Appraisal".

WORD has been received of the death of Dr. A. H. Meyer, Associate Soil Technologist, Louisiana Agricultural Experiment Station. Dr. Meyer died from injuries received in an automobile accident.

THE ALL UNION ACADEMY OF SCIENCE announces that the new soil map of the European part of the Soviet Union is almost completed. This map is made on the scale of 1 to 1,000,000, and has been prepared under the supervision of Prof. Prassolov who attended the Soil Congress in Washington in 1927 and whose maps attracted considerable attention there. The soil map of the Asiatic part of U. S. S. R. is also being prepared and will probably be ready in 1935. Professor Polynov is also preparing a soil map of Asia Minor.

THE ACADEMY OF SCIENCES of U. S. S. R. has issued a memorial volume devoted to Prof. K. K. Gedroitz, who was President of the International Soil Science Congress held in U. S. S. R. in 1930 and who was one of the leading Soviet pedologists. The volume contains a biography of Prof. Gedroitz by G. N. Botch, also addresses by Prof. L. I. Prassolov on "Influence of Gedroitz on Soil Science", by I. V. Turin on "Prof. Gedroitz's Accomplishments in the Field of Soil Chemistry", and by N. I. Sokolov on "Gedroitz's Works Along Soil Fertility Problems". There are also a number of articles contributed by pupils of Prof. Gedroitz and other articles describing his methods and accomplishments in the study of soil complexes.

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